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Design and Control of Concrete Mixtures

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DESIGN *and* CONTROL *of* CONCRETE MIXTURES

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FOREWORD

THE three fundamental considerations which should determine the design of concrete structures are strength, durability and economy. Strength and economy have long been considered the determining elements. These should not, however, be allowed to obscure the equally important requirement of durability. Too much emphasis on the element of economy in construction may lead to methods and practices not suitable to the production of concrete of proper resistance to the elements.

Fortunately, the factors which govern the strength of concrete affect with equal importance the resistance to percolation of water and to weathering. Once this fact is pointed out, the vast experimental data on the strength of concrete are made available for use in the solution of the problems of making durable structures.

The application of the water-cement ratio principle gives a very easy method of designing concrete mixtures for definite qualities. Its simplicity recommends it. Involved calculations are not necessary. In this booklet, which is a revision of an earlier publication carrying the same title, the proportioning of mixtures by trial is recommended. Several years of practical application have demonstrated this method to be most suitable for all conditions. A general treatment of the factors essential to the economic production of concrete of proper strength and durability is included. Particular emphasis is placed on the selection of materials, the mixing and placing of concrete, and protection during curing, also upon the importance of proper workability in the design of the mixture.

DESIGN AND CONTROL OF CONCRETE MIXTURES

FUNDAMENTAL REQUIREMENTS OF CONCRETE

CONCRETE is a mixture of portland cement, water and inert materials put in place in a plastic condition but hardening soon after due to the process known as the hydration of the cement. Although concrete is placed in a plastic condition and cannot be tested for quality at the time of fabrication, it is now practicable to produce concrete of any quality that may be necessary to meet the requirements of the work by proper control of the proportioning, making and placing together with the subsequent curing.

The fundamental requirements of hardened concrete are *strength*, *durability* and *economy*. Fresh concrete must be *workable*, that is, it must be of such a consistency and physical make-up that it can be readily placed in the form without segregation of the materials and without requiring an excessive amount of spading to completely fill the form. *Uniformity* in both the fresh and hardened concrete is necessary to secure economy of materials, to facilitate handling and placing and to obtain uniformity in the completed structure. It is particularly important where watertightness is required.

Most concrete is designed on the basis of compressive *strength*. However, the flexural and tensile strength, the bond with steel reinforcement, and the resistance to wear are in general governed by the same factors which govern the compressive strength. The compressive strength, therefore, may be used as an indication of these other qualities and, since the test for compressive strength is comparatively simple, it is the test that is most often adopted.

If structures are to give long service, the *durability* of the materials is just as important as the strength. In much of the past practice this has not been fully appreciated and too much emphasis has been placed on strength and economy alone. The most important requirement for durability of exposed concrete is watertightness. Durable concrete requires sound, durable aggregates thoroughly incorporated in a cement paste that is watertight.

While *economy* of materials is important, there are other factors affecting the economy of concrete which seldom receive proper consideration. The amount of labor required in placing and finishing concrete is a considerable item in the total cost. It can be reduced to a minimum by proportioning the materials to produce a plastic mixture that can be placed easily under the particular conditions of the job. The most economical concrete does not always result from the mix having the lowest cement factor nor the mix with the lowest cost for materials, but rather from the mix for which *total* cost—materials, handling and placing—is the lowest.

The *workability* required will be different for different classes of work and will be determined by the methods of transporting and the details of placing—width and depth of forms and spacing of reinforcement. Plastic concrete may be regarded as a mass of aggregate particles, individually floated in a cement paste. This gives a mass that can be transported without segregation and can be placed easily in such a manner that when the forms are removed the hardened concrete will have smooth surfaces, free from honeycombing. Concrete of such consistency will require a minimum amount of finishing. In much of the practice in the past, such concrete has not been obtained. This was largely due to the fact that arbitrary mixtures were specified which did not permit adjustments in the mix to suit the character of materials, the condition in which they were measured or the placing requirements of the job. In the endeavor to obtain workable mixtures, excess water was often added which almost invariably resulted in segregation, porosity and low strength.

Uniformity is important since all parts of a structure designed for the same strength should be made of concrete of the same quality. Moreover, the best economy can be obtained only by the use of uniform batches of concrete. Uniformity is best secured by using plastic concrete made homogeneous by thorough mixing of uniformly measured quantities of materials, including the water.

The above fundamental requirements can be obtained by attention to each of the four major factors which determine concrete quality. These are the use of **suitable materials, correct proportioning, careful methods of production, and protection during the curing period.** The selection of materials (see page 19) can best be treated after their desirable characteristics have been brought out in the discussion of proportioning. Production methods including measurement of quantities, mixing, transporting, placing and curing have an important influence on the quality of the finished concrete. These are discussed on page 27. Because of its importance and its relations to the other factors, the proportioning of mixtures is discussed first.

PROPORTIONING CONCRETE MIXTURES

Effect of Mixing Water on Strength

As a result of extensive research in both laboratory and field, a method of proportioning has come into extensive use whereby the properties of the concrete can be predicted with considerable accuracy at the time of fabrication. This method is based on the relation that exists between the strength and other properties of concrete and the amount of mixing water used. The fundamental law has been well established and may be stated as follows:

> **For plastic mixes using sound aggregates, the strength and other desirable properties of concrete under given job conditions are governed by the net quantity of mixing water used per sack of cement.**

The strength of concrete at a given age, therefore, will be determined by the amount of water used with each volume of cement, regardless of what quantities of aggregates are used, *so long as the mixture is plastic and workable* and the aggregates are clean and made up of sound particles. This principle may be more readily understood if the cement paste is thought of as a glue binding the aggregate particles together. Increasing the water content dilutes the glue and reduces the strength. Not only is the compressive strength reduced by additional water but, likewise, the flexural and tensile strength, the bond between steel and concrete and the resistance to wear are reduced.

Effect of Mixing Water on Durability

The resistance of concrete to severe conditions of weathering and to the action of sea and sulphate water is determined largely by the degree of impermeability or watertightness*. While the influence of the water content of the paste on the watertightness of the concrete is not so well established experimentally as its influence on the strength, the relation is a fundamental one that is easily explained. During the process of hydration a certain amount of water chemically combines with the cement to become solid matter, a permanent part of the structure. The amount, however, is small, depending upon the extent of curing, and is much less than the amount of water required to make plastic concrete. Water which does not enter into combination still remains distributed within the paste and the space it occupies will be represented by air voids as the water evaporates. The more water used in mixing, the larger and more numerous will be these air voids, forming ready channels for the passage of water which may be later brought in contact with the concrete. A low water-cement ratio will produce a paste in which the voids are so minute and so well distributed that the paste will be watertight. Such a paste used with aggregate quantities to give a plastic homogeneous mass will produce impervious concrete.

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*For discussion on watertight concrete see page 38.

Proportioning Mixtures for Quality

It will be seen that the quality of concrete, so far as proportioning is concerned, is determined by the quality of the water-cement paste and that the relative amounts of aggregate and cement are important only insofar as they affect the workability and cost.

Designing a concrete mix, therefore, consists in selecting the water-cement ratio which will produce concrete of the desired strength and resistance to exposure and finding the most suitable combination of aggregates which will give the necessary workability when mixed with cement and water in this ratio.

DESIGN OF CONCRETE MIXTURES

SELECTION OF WATER-CEMENT RATIO

The selection of a water-cement ratio as the basis for designing a concrete mixture involves a consideration of both the strength requirements and the degree of exposure to which the concrete is to be subjected. The water-cement ratio strength law can be represented by a curve, as in Fig. 1. In this figure Curve "A" represents the results of thousands of tests made at the Structural Materials Research Laboratory* a few years ago. Subsequent investigations at this laboratory indicate that somewhat higher strengths may now be expected where workmanship and conditions of tests are well controlled. This is due largely to the steady improvement that is being made in the quality of portland cement. Investigations at other laboratories and in the field have given similar curves, in some cases higher and in other cases lower than Curve "A." Since Curve "A" is the result of a large number of tests and is conservative it may be used generally as the basis of design with average materials where the water-cement ratio is carefully controlled by accurate measurement of quantities of water, cement and aggregate, with proper correction for moisture carried by the aggregate.

Selection From Job Curves

While the relation between water-cement ratio and compressive strength will vary for different conditions, the exact relation may be determined for any given set of conditions. Tests may be made using the materials proposed for the job and duplicating as nearly as possible the expected conditions of manipulation. From the results of these tests a "job curve" may be drawn. A typical job curve is shown in Fig. 1. The curve should be established for a range of values including all of the strengths called for in the plans. The tests should include at least four different water-cement ratios and at least four specimens for each water-cement ratio as recommended in the Tentative Building Regulations for Reinforced Concrete adopted by the American Concrete Institute in 1928. Additional tests should be made as the work proceeds. Reliance should be placed on a job curve only where the tests are conducted by a competent engineer who is experienced in the testing of materials. The standard methods of the American Society for Testing Materials for making tests should be followed in all cases. Some margin of safety should be allowed to provide for uncontrollable variations in job conditions and it is suggested that in selecting the water-cement ratio from a job curve the concrete should be designed for strength 15 per cent higher than indicated on the curve. For example, if the job curve in Fig. 1 represents conditions on a certain project and it is desired to produce concrete having a compressive strength of 3000 pounds per square inch, the water-cement ratio is selected for 3450-pound concrete, in this case permitting a maximum of 6 gallons of water per sack of cement. Since Curve "A" represents a much larger number of tests and is conservative for materials now available, it is not considered necessary to allow this margin of safety with its use.

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*Experimental studies of concrete and concrete materials formerly carried out by the Structural Materials Research Laboratory through the co-operation of the Lewis Institute and the Portland Cement Association are now being continued at the Research Laboratory of the Portland Cement Association.

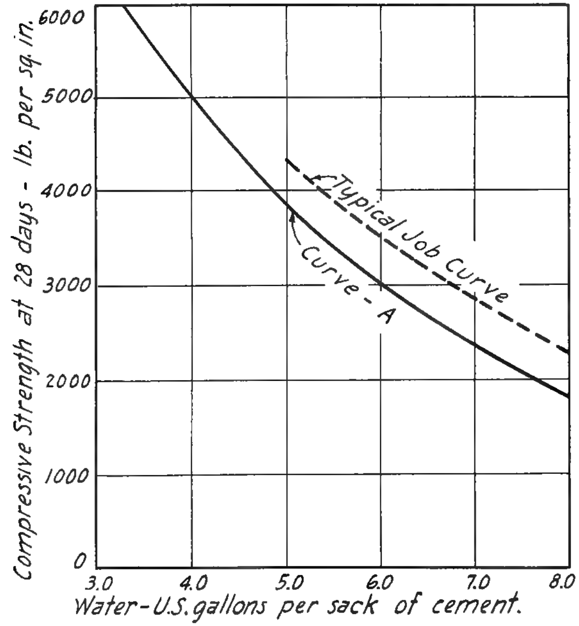


Fig. 1—Effect of quantity of mixing water on the strength of concrete. Curve "A" is based on average values from nine series of tests made over a period of four years. In the absence of field tests, it may be used for design where the water-cement ratio is carefully controlled by accurate measurement of quantities of water, cement and aggregate with proper correction for water carried by the aggregate. The job curve is a representative curve obtained from tests of the materials to be used on a specific project.

Water-Cement Ratios for Exposed Concrete

Table I may be used as a guide in selecting the water-cement ratio where the conditions of exposure require a higher class of concrete than necessary to meet the strength requirements. A number of types of structures is given in each group as suggestive; the exact classification in individual cases or of other types will depend upon the conditions of exposure at the particular site. The classification given is based on conditions prevailing in the greater part of the United States and assumes proper workability of the mixture, thorough mixing, placing the concrete by puddling to completely fill

TABLE I
CLASSES OF CONCRETE FOR DIFFERENT DEGREES OF EXPOSURE

Type of Structure	Degree of Exposure	U. S. Gal. of Water* per Sack of Cement
Walls, dams, piers and other structures exposed to sea or alkali waters.	Extreme	5½
Walls, dams, piers, reservoir linings, etc., exposed to alternate wetting and drying in fresh water in northern climate. Watertight structures. Sewers, pressure pipe, tanks, piles, athletic stadia, pavements, all thin structural members exposed to severe weather and frost action.	Severe	6
Walls, dams, piers, reservoir linings exposed to fresh water in southern climate. Exterior columns and beams of reinforced concrete buildings. Basement walls. Thin structural members of all types exposed to moderate weather and frost action.	Moderate	6¾
Ordinary enclosed structural members. Heavy piers and retaining walls in moderate exposure. Mass concrete, footings, etc., protected from alternate wetting and drying and from severe weather conditions.	Protected	7½

*These quantities should not be exceeded even when resultant strength is higher than required for structural stability. Free water or moisture carried by the aggregate must be included as part of mixing water.

the form and incorporate the reinforcement, and thorough protection from drying out or low temperature during the early hardening period.

In proportioning concrete for exposure, the water-cement ratios recommended in this table often result in concrete strengths that seem unnecessarily high. In order to assure concrete of the quality required to withstand the conditions of exposure, these water-cement ratios should not be exceeded. Perhaps the chief cause of unsatisfactory concrete in the past has been a tendency to rely on strength requirements alone in proportioning concrete for structures subjected to water pressure or severe weathering.

Selection of Consistency

The design of a concrete mix involves consideration of the requirements to be met in handling and placing the concrete and the factors affecting economy. In describing the character of fresh concrete, three terms are most often used—**consistency, plasticity and workability.** "Consistency" is a general term relating to the state of fluidity of the mix and embraces the entire range of fluidity from the driest to the wettest

View showing stiff, medium and wet mixtures of concrete. For foundation footing walls, pavements, floors and work of like character the stiff consistency is recommended. The medium mix will be found suitable for tank walls and floors, slabs, beams, etc. The wet mix is suitable for thin walls and columns.

possible mixtures. It requires a qualifying term for definiteness. The term "plasticity" is used to describe a consistency of concrete which can be readily molded but which permits the fresh concrete to change form slowly if the mold is removed. A plastic mass does not crumble but flows sluggishly without segregation such as occurs in the wetter mixtures. Thus, neither the very dry, crumbly mixes nor the very fluid, watery mixes are regarded as of plastic consistency. In this connection it may be pointed out that a low water-cement ratio does not necessarily mean a dry consistency.

The term "workability" is used to describe the ease or difficulty which may be encountered in placing the concrete in a particular location. The conditions under which the concrete is to be placed are, therefore, involved —size and shape of the member, spacing of reinforcing rods or other details interfering with the ready filling of the forms. It is obvious that a stiff plastic mixture with large aggregate, which is workable in a large open form, would not be workable, for example, in a thin wall of complicated reinforcing details.

Rodding concrete for slump test.

The Slump Test

A rough measure of the consistency that may be used is the slump test which should be made in accordance with the "Tentative Method of Test for Consistency of Portland Cement Concrete" of the American Society for Testing Materials given on page 63. This test is not an absolute measure of workability and it should not be used to compare mixes of wholly different proportions or of different kinds of aggregates. Under conditions of uniform operations, however, changes in consistency as indicated by the slump are useful in indicating changes in the character of the material, the proportions or the water content. To avoid mixes too stiff or too wet, slumps falling within the limits given in Table II are recommended. This table lists a few kinds of structures as typical examples for each range of slumps.

Measuring the slump.

TABLE II
RECOMMENDED SLUMPS FOR CONCRETE

Type of Structure	Slump—Inches Minimum	Slump—Inches Maximum
Massive sections, pavements and floors laid on ground	1	4
Heavy slabs, beams or walls	3	6
Thin walls and columns, ordinary slabs or beams	4	8

SELECTION OF AGGREGATE COMBINATION

In determining the proportions of materials it is desirable to arrive at those proportions which will give the most economical results consistent with proper placing. The relative proportions of fine and coarse aggregates and the total amount of aggregate that can be used with fixed amounts of cement and water will depend not only on the consistency of concrete required but also on the grading of each aggregate. A combination of aggregates made up largely of coarse particles presents less total surface to be coated with cement paste than aggregate of fine particles and is therefore more economical. For this reason it is desirable to use the lowest proportion of fine aggregate which will properly fill the "void" spaces in the coarse aggregate.

Aggregates that are graded so that they contain many sizes are more economical than aggregates in which one or two sizes predominate because the former contain fewer voids. The small particles fill the spaces between the larger particles which otherwise must be filled with cement paste. A properly proportioned combination of well-graded fine and coarse aggregates contains all sizes between the smallest and the largest without an excessive amount of any one size. The best grading, however, is not necessarily one consisting of equal amounts of the various sizes and such a grading is seldom practicable. Satisfactory mixtures can usually be obtained with the commercial aggregates by proper combination of fine and coarse aggregates.

Proportions of Fine and Coarse Aggregate

Increasing the proportion of coarse aggregate up to a certain point reduces the cement factor. Beyond this point the saving in cement is very slight, while the deficiency in mortar increases the labor cost of placing and finishing. Because coarser gradings are more economical, there has been a tendency to use mixtures that were undersanded and harsh. Harshness has been the principal cause for over-wet mixtures, resulting almost invariably in honeycombing in the finished work. While increasing the proportion of fine materials makes for smoother working mixes, excessive proportions of fine present greater surface areas to be coated and more voids to be filled with cement paste. Under such conditions the total amount of aggregate which can be used with fixed amounts of cement and water is greatly reduced.

The foregoing factors fix within rather narrow limits the range of proportions which can be used with economy. Table III indicates the usual limits in the proportions of fine and coarse aggregates for several sizes using water-cement ratios of 7½ gallons or less per sack of cement with plastic and workable mixes.

TABLE III
RECOMMENDED PROPORTIONS OF AGGREGATES

Maximum size of coarse aggregate—inches	Ratio of fine* to total aggregate on basis of dry, compact volumes, measured separately	
	Minimum	Maximum
⅜	0.55	0.70
¾	0.40	0.60
1 and over	0.30	0.50

*The finer the sand, the lower will be the percentage required.

Proportion of Total Aggregate to Cement

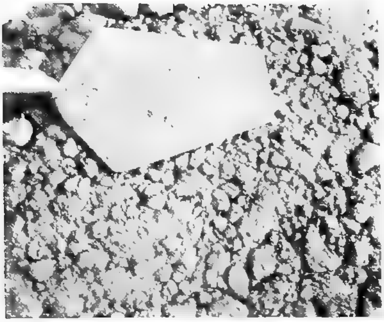
The *total amount* of aggregate that can be used with given amounts of cement and water will depend on the consistency required by the conditions of the job. A stiffer mix permits more aggregates to be crowded into the cement paste and thus gives a larger volume of concrete. Stiffer mixes cost less for materials than the more fluid mixes but the cost of handling and placing increases when excessively dry mixes are used. On the other hand, mixes that are over-wet require high cement factors and cannot be placed without segregation of the materials. Such mixes are uneconomical in material and are seldom required for the conditions of placing. In many instances, where correct proportions of sand are used, it will be found practicable to use somewhat stiffer mixtures than have been the practice in the past without adding materially to the cost of handling or placing.

Because of the restrictions imposed by limiting the amount of water for each sack of cement, experienced foremen can generally be depended upon to obtain a proper balance between the various factors, with the result that the concrete will be neither harsh nor honeycombed on the one hand nor porous and over-wet on the other.

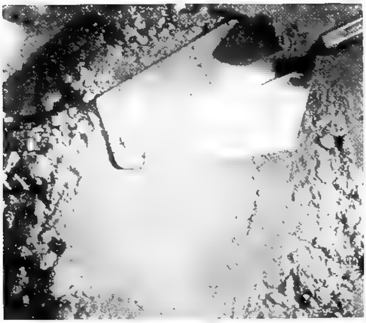
One of the important advantages to the contractor of the water-cement ratio method is that the materials may be proportioned to facilitate handling and placing, thereby reducing the cost of these items. With some latitude open in the matter of workability and proportions he will be quick to select those mixes which give him the necessary workability at the lowest cost. At the same time such a mixture will thoroughly fill the forms and reduce the cost of patching honeycomb spots to a minimum. Where the surfaces are to be given a special treatment, the process is invariably made easier.

PROPORTIONING CONCRETE MIXTURES BY TRIAL

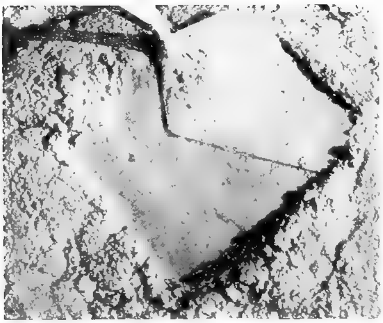
There is little difficulty in arriving at a suitable mix with fixed proportions of cement and water as this can be done by actual trial, making adjustments in the proportions until concrete of the desired character is obtained. In many localities contractors are familiar with the available materials and they know the approximate mix which can be used under given conditions. For estimating purposes some contractors prefer to make small trial batches in advance of the job, using samples of various aggregates submitted for the work. When concreting is to start on the job, full-sized trial batches may be made in the mixer, using the aggregates selected for the job.



A concrete mixture in which there is not sufficient cement-sand mortar to fill spaces between pebbles. Such a mixture will be hard to work and will result in rough, honeycombed surfaces.



A concrete mixture which contains correct amount of cement-sand mortar. With light troweling all spaces between pebbles are filled with mortar. Note appearance on edges of pile. This is a good workable mixture and will give maximum yield of concrete with a given amount of cement.



A concrete mixture in which there is an excess of cement-sand mortar. While such a mixture is plastic and workable and will produce smooth surfaces, the yield of concrete will be low. Such concrete is also likely to be porous.

Trial Batches in Advance of Job

For the small, preliminary batches it will be found convenient to use 1/10 sack of cement as this size of batch can be mixed by hand in a pan or wheelbarrow. Since only small quantities of aggregate are involved, these may be surface-dried so that correction for moisture will not be necessary. A given quantity of each aggregate is measured either by volume or by weight. A paste is then prepared consisting of cement and water in the ratio selected and the surface-dried aggregates added to the paste until the batch has stiffened to the desired consistency. It should be remembered that, while a low percentage of fine aggregate permits higher yield, there must be sufficient fine aggregate to enable the operator to trowel the mass to a smooth finish.

Several trial batches should be made to find the combination of materials which will give the best workability and at the same time produce a good yield.

In some markets there are several different kinds of aggregates available which are suitable for most concrete work and which will meet the requirements of the specifications. The small batches suggested above are especially useful to compare the results that may be expected with these aggregates and will assist the contractor in selecting the materials which will produce the desired quality of concrete most economically.

Trial Batches on Job

When concreting operations are started, full-sized trial batches may be made in the mixer, using the aggregates selected for the job. When the contractor is not sufficiently familiar with local materials to estimate the proportions for the first batch, they may be based on the preliminary small batches, or Table IV may be used as a guide in selecting a trial mix. The mixes given in this table are based on dry, compact volumes and proper allowance must be made for loose measurement and the effect of bulking due to moisture. Values should not be taken from this table for estimating purposes as the actual proportions required to give the desired workability with the job materials may vary somewhat from the proportions indicated.

The appearance of this first batch and the ease or difficulty with which it is puddled into the forms will determine what change should be made in the second batch. The most important questions to settle are the relative amounts of the fine and coarse materials and the total amount of aggregate to use

TABLE IV. TRIAL MIXTURES FOR VARIOUS WATER-CEMENT RATIOS

Water-cement ratios indicated include moisture contained in the aggregate.

Proportions are given by *volume, aggregate dry* and *compact.* Thus 1-2-3½ indicates 1 volume of cement, 2 volumes of sand and 3½ volumes of coarse aggregate.

If the aggregates are to be measured in the *damp* and *loose* condition they will occupy greater volume than when dry and compact. Amount should be determined by test. Approximate average value for sand 20 per cent, for coarse aggregate 6 per cent.

For approximate proportions *by weight* add 15 per cent to proportions of aggregate shown in the table.

The mixes are given as a *guide only.* The first batch should be made with measured water content and the proportions thereafter adjusted to give the desired workability, maintaining the specified water-cement ratio.

Slump Inches	Trial Mix, Dry Compact Volumes for Maximum Size of Aggregate Indicated	
	1 inch	2 inches
Water-Cement Ratio 5½ Gallons per Sack		
½-1	1-2-3	1-2-3½
3-4	1-1¾-2½	1-1¾-3
5-7	1-1½-2	1-1½-2½
Water-Cement Ratio 6 Gallons per Sack		
½-1	1-2¼-3¼	1-2¼-4
3-4	1-2-3	1-2-3½
5-7	1-1¾-2½	1-1¾-3
Water-Cement Ratio 6¾ Gallons per Sack		
½-1	1-2½-3½	1-2½-4
3-4	1-2¼-3¼	1-2¼-3¾
5-7	1-2-3	1-2-3½
Water-Cement Ratio 7½ Gallons per Sack		
½-1	1-3-4	1-3-4¾
3-4	1-2½-3¾	1-2½-4¼
5-7	1-2¼-3½	1-2¼-3¾

with each sack of cement. Since the quantities used in charging the mixer are known, it will be a simple matter to compute the cost of the finished concrete for the various batches if the skip into which the mixer discharges is calibrated to indicate the volume of concrete produced, or this yield may be calculated by the method on page 17. After several trial batches, using varying proportions of coarse and fine, the most desirable mix can be determined from a consideration of the cost per cubic yard and the degree of workability obtained.

The essential factors in such a series of trials are that the selected water-cement ratio be accurately maintained and that the resulting mixtures are really workable. The experienced concrete foreman should have no difficulty in selecting the combination most suited to the work at hand, as the requirements of placing almost invariably prevent the use of mixtures that are too harsh. The less experienced man may, in his desire to obtain the greatest possible yield, use a larger proportion of coarse aggregate than is desirable for ease of placing and freedom from honeycombing. This condition, of course, should be guarded against.

Correction for Moisture and Absorption

All aggregates as used under job conditions contain more or less moisture. Since this moisture becomes a part of the mixing water, the amount must be determined to make the proper correction in the quantity of water to be added to the batch. Methods for determining moisture content of aggregates are given on page 24.

For example, suppose that concrete containing 6¾ gal. of water per sack of cement is desired, using a 3 to 4 in. slump with aggregate of 1 in. maximum size. The mix suggested in the table is 1-2¼-3¼. Assume that it has been found by test that the sand bulks 20 per cent and the coarse aggregate 6 per cent due to moisture and loose measurement. (See page 24 for discussion on bulking.) The corresponding mix for the materials as measured in the field will then be 1-2¼x1.20-3¼x1.06 = 1-2.7-3.4. Assume also that it is found that the fine aggregate contains ½ gallon of water per cu. ft. (loose measurement) and the coarse aggregate ¼ gallon per cu. ft., each in excess of the absorption.

Then:

Moisture in fine aggregate = 2.7x½ = 1.35 gal.
" " coarse " = 3.4x¼ = .85 "
Total = 2.20 or say 2¼ gal.

The amount of water to be added at the mixer is therefore 6¾ − 2¼ = 4½ gallons per sack of cement.

When tests for moisture in the aggregates cannot be made, approximate values may be based on the following table:

APPROXIMATE QUANTITY OF SURFACE WATER CARRIED BY AVERAGE AGGREGATES*

Very wet sand	¾ to 1 gal. per cu. ft.
Moderately wet sand	about ½ gal. per cu. ft.
Moist sand	about ¼ gal. per cu. ft.
Moist gravel or crushed rock	about ¼ gal. per cu. ft.

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*The coarser the aggregate, the less free water it will carry.

In correcting for moisture in the aggregate it is only the free or surface water that must be taken into account. When dry aggregates are used, allowance may be made for the absorption which takes place in the aggregate during the period of mixing and handling. For this purpose the absorption during a period of 30 minutes may be used. Tests for absorption of sand may be made in accordance with the Recommended Practice of the American Society for Testing Materials (1920 Proceedings, Part I, Appendix 2, of Report of Committee C-9). A test for absorption of coarse aggregate is described on page 71. In the absence of tests, average quantities given below may be used as a basis:

APPROXIMATE ABSORPTION OF AGGREGATES

Average sand	1.0 per cent by weight
Pebbles and crushed limestone	1.0 per cent by weight
Trap rock and granite	0.5 per cent by weight
Porous sandstone	7.0 per cent by weight
Very light and porous aggregate may be as high as	25 per cent by weight

Most aggregates as used on the job are damp and contain more moisture than the equivalent of the absorption. The amount of free moisture is found by subtracting the absorption from the total amount of moisture. Thus, if moist sand is found to contain 5 lb. of water per cu. ft. and has absorption of 1 lb. per cu. ft., the effective quantity of water which becomes part of the mixing water is 4 lb. per cu. ft. and the quantity to be added to each batch should be calculated on this basis.

Other Methods of Proportioning

Various other methods of proportioning have been used to some extent. Another method based on the water-cement ratio principle is the fineness modulus method in which established results from a large number of tests are used. Sieve analyses of the aggregates are made and, from these analyses, grading factors designated as fineness moduli are determined. From these determinations the approximate mixes for various consistencies may be found. The method is useful for comparing materials and studying the inter-relation of mix, consistency and grading. It involves more tests and calculations than the trial method which is practical, easy to apply and produces the desired results.

Quantities of Materials

The quantities of materials in a concrete mixture may be determined accurately by making use of the fact that the volume of concrete produced by any combination of materials, so long as the concrete is plastic, is equal to the sum of the *absolute* volume of the cement plus the *absolute* volume of the aggregate plus the volume of water. The absolute volume of a loose material is the actual total volume of solid matter in all the particles. This can be computed from the weight per unit volume and the apparent specific gravity as follows:

$$\text{Absolute Vol.} = \frac{\text{unit weight}}{\text{apparent specific gravity} \times \text{unit wt. of water } (62\frac{1}{2}\text{ lb. per cu. ft.})}$$

in which the unit weight is based on surface dry aggregate.

The method can best be illustrated by an example. Suppose the concrete batch consists of 1 sack of cement (94 lb.), 2.2 cu. ft. of dry fine aggregate weighing 110 lb. per cu. ft. and 3.6 cu. ft. of dry coarse aggregate weighing 100 lb. per cu. ft. and is to be mixed with a water-cement ratio of 7 gallons per sack. The apparent specific gravity of the cement is usually about 3.1 and of the more common aggregates about 2.65. The volume of concrete produced by the above mix is calculated as follows:

Cement = 1 cu. ft. @ $\frac{94}{3.1 \times 62.5}$ = .49 cu. ft. abs. vol.

Fine Aggregate = 2.2 cu. ft. @ $\frac{110}{2.65 \times 62.5}$ = 1.46 " " " "

Coarse Aggregate = 3.6 cu. ft. @ $\frac{100}{2.65 \times 62.5}$ = 2.18 " " " "

Volume of Water = $\frac{7.0}{7.5}$ = .93 " " " "
Total Volume of Concrete Produced = 5.06 cu. ft.

Thus 1 sack of cement produces 5.06 cu. ft., neglecting absorption or losses in manipulation. The cement required for one cubic yard of concrete is, therefore, $\frac{27}{5.06} = 5.34$ sacks or 1.33 barrels. The quantities of fine and coarse aggregate required can be found from a simple computation based on the number of cubic feet used with each sack of cement; thus, for the fine aggregate $\frac{5.34 \times 2.2}{27} = .43$ cu. yd. and for the coarse aggregate $\frac{5.34 \times 3.6}{27} = .71$ cu. yd.

For unusual materials such as blast furnace slag, special light weight aggregates, etc., the exact apparent specific gravities should be used. It will be found that, for the purpose of estimating quantities, the average value of 2.65, given previously, will be sufficiently accurate for sand and gravel and the common varieties of crushed rock. The method of determining the apparent specific gravity is given on pages 60 and 63.

CONTROL OF CONCRETE IN THE FIELD

Once a satisfactory and economical mixture for the required water-cement ratio has been obtained, there remains the problem of producing this mixture on the work in such a manner that there is delivered to the place of deposit a continuous supply of concrete, each batch of which is as nearly like the other batches as it is possible to be. Uniformity in this sense refers not only to water-cement ratio (and therefore strength) but also to consistency, since nothing quite so disorganizes the work of placing concrete as to have the consistency vary continually from one extreme to the other. The essential factors in the proper control of the quality of concrete in the field may be summarized as follows:

Selection of suitable materials.
Design of mix for quality, workability and economy.
Control tests for suitability of materials and uniformity of concrete.
Accurate measurement of materials.
Thorough mixing of concrete.
Suitable means of transportation.
Proper care in placing and finishing to prevent segregation.
Adequate curing as regards moisture and temperature.
Follow-up tests of concrete to confirm quality.

The design of the mix has been discussed and needs emphasis here only to point out the importance of proper workability of the mix in its relation to the problems of transporting and placing. Whatever equipment and methods are used for transporting and placing, the mix should be designed so as to avoid segregation during these processes and to permit puddling without excessive spading or the accumulation of water or laitance on the surface.

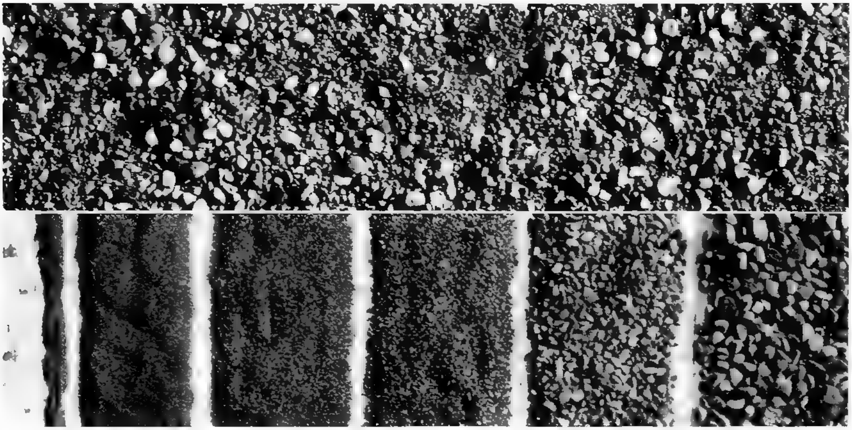
SELECTION OF MATERIALS

Cement

Portland cement should conform to the Standard Specifications and Tests for Portland Cement (Serial Designation: C9-26) of the American Society for Testing Materials.

Water

The water should be suitable for drinking unless it is known by test or experience that other waters are satisfactory. Sea water should not



Sample of well-graded sand before and after it has been separated in various sizes. Particles vary from fine up to ¼ inch in size. This is good sand for concrete work. For good workability, at least 5 per cent should pass a 50-mesh sieve.

be used for mixing concrete on account of the danger of corrosion of steel reinforcement.

Aggregates

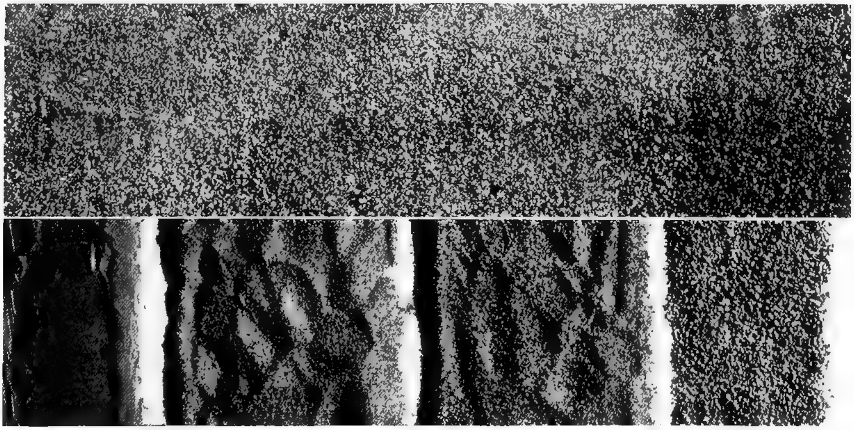
Aggregate is an inert mineral filler used with the water-cement paste for economy. All aggregates should consist of inert materials that are clean, hard, strong and durable. The particles should not be coated with clay or dirt since this prevents proper bonding of the paste. Weak, friable or laminated materials are undesirable. Shale and stones laminated with shale are especially to be avoided. A visual inspection will usually disclose any weakness in the coarse aggregate. If any doubt exists, the aggregate may be tested in concrete specimens. For exposed structures, where durability is important, only aggregates of proven resistance to the particular type of exposure should be used. A good specification for aggregates is that they meet the requirements of the "Tentative Specifications for Concrete Aggregates" of the American Society for Testing Materials given on page 52.

It is very important that only clean aggregates are used in concrete. Dirty aggregates may lead to failure even with proper water control if the dirt is of the kind to prevent hardening of the cement or to lead to disintegration. Even if the extraneous material does not lead to failure, its presence may greatly increase the cost, because it requires more water for workability, which, with a fixed water-cement ratio, means a richer mix.

The size and grading of the aggregates are important from the standpoint of economy, as they have a very decided effect on the workability of the concrete and the amount of concrete that can be produced from a given volume of cement when used with a fixed proportion of water. With fixed proportions of cement and water and with a given condition of workability a greater volume of aggregates can be used when coarsely graded than when made up of the smaller sizes. Greater economy can therefore be realized by using aggregate containing all sizes but in which the coarser sizes predominate.

While coarse gradings tend to economy, they also tend to produce harsh mixtures. In well-graded aggregates the particles vary in size from the smallest to the largest. The fine particles are necessary for workability and smoothness of mixtures. This is especially true of the fine particles in the sand, a certain amount of which must be present. The American Society for Testing Materials specifies that from 2 to 30 per cent of fine aggregate pass a 50-mesh sieve, while the 1924 Joint Committee Report recommends 10 to 30 per cent. Sand is sometimes stripped of the fine material which is sold for use in plaster and the balance disposed of as concrete sand. Such sand is usually unsatisfactory at least for building purposes. The washing process sometimes removes too much of the fines and certain adjustments are necessary in the washing plant to retain some of this material.

The maximum size of aggregate is governed by the nature of the work. In thin slabs or walls the largest pieces of aggregate should never exceed about ⅕ to ¼ the thickness of the section of concrete being placed. In reinforced concrete, specifications usually limit the maximum size to three-fourths of the minimum clear spacing between



Sample of poorly graded sand which lacks particles coarser than 1/16 inch in size, showing how it looks when separated into four sizes. Ordinarily such a sand is not as economical as sand of coarser grading.

reinforcing bars. In this connection the maximum size is regarded as the clear space between the sides of the smallest square opening through which 95 per cent by weight of the material can be passed.

Since grading is largely a matter of economy, too great restrictions in this respect are undesirable in the general specification except clauses to insure uniformity. The engineer and architect should be chiefly concerned with the quality and cleanness and the specifications should cover these with definite limits and tolerances. The contractor should have considerable leeway in the selection of materials. He should purchase aggregates under a definite specification, rigid enough to meet fully the requirements of the work but containing no unnecessary restrictions which will increase the cost or restrict the supply. His purchases may be based on samples of the selected materials with permissible variations and tolerances.

CONTROL TESTS

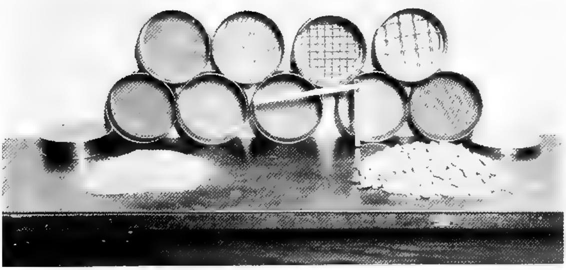
Before concreting operations have started and during the entire progress of the work it is desirable to make certain tests of the materials. Some of these are to determine the suitability of the aggregates for the work and others are necessary to properly control the concrete so that uniform batches are produced by making proper adjustments in the mix for variations in the materials.

Sampling Aggregates

In all tests it is important that the samples of aggregates be representative of the materials as used on the job. The standard methods of sampling described on page 54 should be followed carefully. Reducing the large field samples to small quantities for the individual tests should also be done with care so that the final sample will be representative. This may be done by the quartering method. The aggregate sample, thoroughly mixed, is spread on a piece of canvas in an even layer 3 or 4 inches thick. It is then divided into four equal parts and two opposite parts discarded. This process is repeated until the desired size of sample remains. For fine aggregate a sand splitter may be used.

Quartering aggregate sample. See standard method of sampling aggregates.

Test for Organic Impurities



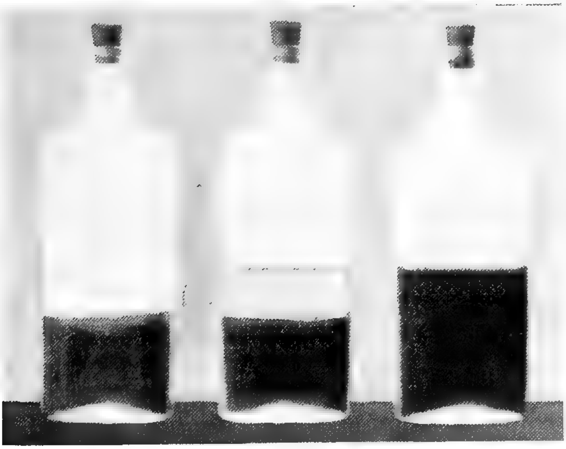
Standard set of laboratory sieves.

The suitability of fine aggregate from the standpoint of organic matter may be determined by the "Colorimetric Test for Sands" described on page 57. Sands which give a darker color than the standard should not be used for important concrete work without further investigation. In some sands there are, however, small quantities of coal or lignite which give the liquid a very dark color. The quantity may not be sufficient to reduce the strength appreciably and the sand may otherwise be acceptable. In such cases mortar strength tests of the sand in question should be made to determine the exact effect of the impurities present. For use in concrete exposed to weathering appreciable quantities of coal or lignite in aggregate are not desirable, as they are not durable under these conditions.

Tests for Silt

The "Tentative Method of Decantation Test for Sand and Other Fine Aggregates" given on page 58 may be followed to determine the quantity of clay and silt. An approximate determination for use in the field may be made by the "sedimentation test" given on page 71.

A distinction should be made between silt and fine sand particles passing the 100-mesh sieve. All of the material which passes this sieve is not silt. Thus it is quite possible to have 5 per cent pass the 100-mesh sieve and still have less than 3 per cent



Colorimetric test is used to detect presence of harmful amounts of organic matter in aggregates. A clear liquid as shown in the bottle on the reader's left indicates aggregate is free from organic matter. The slightly colored liquid in the center bottle indicates presence of some organic matter but not enough to prove injurious. The dark liquid in the right hand bottle shows that the aggregate is unsatisfactory for concrete work unless organic matter is washed out.

silt. Only the material removed by the Decantation Test can be regarded as silt.

Test for Grading

The grading of aggregates may be studied by making sieve analyses tests in which the particles are divided into the various sizes by standard sieves. In this way the different materials available may be compared. Where there is a choice, those containing too large a proportion of any one size and in which some of the sizes are lacking should be avoided. The sieve analysis is also useful in checking the uniformity of aggregates and shows whether or not they meet the requirements of the specifications. The sieve analysis should be made in accordance with "Standard Method of Test for Sieve Analysis of Aggregates for Concrete" given on page 58.

Moisture and Bulking

When moisture is added to dry sand, films of water are formed on the surfaces of the particles, fluffing them apart. This causes an increase in the volume, when measured in the loose condition, much greater than the volume of water added, so that a given volume of damp sand may be the equivalent of a much smaller volume of dry sand. This bulking increases rapidly with increases in moisture content until the moisture is about 6 per cent by weight, when the bulking may be as much as 20 or even 30 per cent. Further additions of water tend to flood or pack the sand, decreasing the amount of bulking. When the sand is completely inundated the volume is approximately the same as when measured dry and loose. The finer the material the more it will bulk for a given moisture content. The size of the measure and the method of filling also affect bulking which should be evaluated for each job. Coarse aggregates are little affected in volume by moisture.

The methods of measuring aggregates also cause differences in the actual amount of material measured. For this reason the American Society for Testing Materials has adopted a standard method for determining the unit weight of aggregate which is given on page 59. In this method, the aggregates are dry and compacted. Many tables, such as Table IV on page 15, are based on this standard. On the other hand, aggregates as measured in the field are usually loose and damp, so that proper allowance must be made for the bulking due to loose measurement as well as for that due to moisture.

Tests for Moisture and Bulking

The moisture present in aggregate may be determined by weighing a sample of the damp material, drying the sample and weighing again after drying. The weight per cubic foot of aggregate, surface dry and compact, may be determined by following the standard method given on page 59 and the weight, damp and loose, may be found by filling

TABLE V
BULKING OF AGGREGATE

Item	Sand	Coarse Aggregate
1. Weight of damp sample, ounces........	35.0	32.5
2. Weight of oven dried sample, ounces...	33.0	31.7
3. Weight of water in damp sample (Item 1—Item 2)...........................	2	0.8
4. Per cent of total moisture in terms of dry aggregate $\left(\frac{\text{Item 3}}{\text{Item 2}} \times 100\right)$......	6	2.5
5. Per cent of absorption (assumed)......	1	1
6. Per cent of surface moisture (Item 4—Item 5)............................	5	1.5
7. Weight per cu. ft. damp loose, pounds..	97.2	94.4
8. Weight of surface dry aggregate in 1 cu. ft. of damp loose material, pounds— $\left(\text{Item 7} \times \frac{100}{100 + \text{Item 6}}\right)$..........	92.6	93.0
9. Weight of water in 1 cu. ft. of damp loose material, pounds (Item 7—Item 8)...	4.6	1.4
10. Weight per cu. ft. of surface dry compact aggregate, pounds (by test)......	112.0	99.0
11. Bulking factor $\left(\frac{\text{Item 10}}{\text{Item 8}}\right)$............	1.21	1.06

the same container with damp, loose aggregate, using as nearly as possible the method of filling to be employed on the work. Typical calculations to determine bulking are shown in Table V.

The correction for bulking is made by adding proportionately larger amounts of the bulked aggregate to secure any desired actual volume of dry compact aggregate. Thus, if a dry compact mix of 1-2¼-3½ is to be used with the above aggregates, the proportion based on loose volume of sand will be 2¼ × 1.21 = 2.7 and of the coarse aggregate 3½ × 1.06 = 3.7, giving a field mix of 1-2.7-3.7. To maintain uniform amounts of aggregate at the mixer, allowance for changes in bulking due to changes in moisture content should be made by corresponding changes in the measured proportions. Thus, if the bulking factor of the above sand increases to 1.25, the relative volume of sand in the field mix should be changed to $\frac{1.25}{1.21} \times 2.7 = 2.8$ or by direct calculation 2¼ × 1.25 = 2.8.

The amount of moisture held by the aggregate will vary from time to time with changing weather conditions and with variations in the elapsed time between washing and arrival on the job. In spite of these varying influences the moisture content is surprisingly uniform on most jobs. Changes in moisture content of coarse aggregate will be quite infrequent and once the correction has been made no further adjustments are usually necessary. However, the moisture in the sand may vary sufficiently to affect the mix. When variations in moisture in the aggregates are frequent and difficult to control, the frequency of making changes in the mix may be reduced to a minimum by designing for a somewhat lower water-cement ratio than is specified. Thus, if 7½ gallons of water per sack of cement is specified, the mixture may be designed on the basis of 7 or 7¼ gallons per sack. Changes in the mix will then be necessary only when there is a very large change in the moisture content which will be at such infrequent intervals as to cause little inconvenience or interruption to the operations. Such large variations in moisture content should be readily apparent either from the appearance of the aggregate or the consistency of the concrete and the necessary adjustments may be made quickly to maintain the desired uniformity.

There have been many methods proposed for determining the moisture in aggregate. From the standpoint of speed, accuracy and simplicity in the field, evaporation of the moisture by burning alcohol has given most satisfactory results. The determination is made by placing a weighed sample of the damp sand in a shallow pan, pouring alcohol (about one-third cupful for each pound) over the sand, stirring the mixture with a rod and then spreading it in a thin layer over the bottom of the pan. The alcohol is then ignited and allowed to burn until consumed, the sand being stirred with the iron rod during burning. If the sand still appears damp, it is advisable to repeat the burning process in order to insure complete drying of the sample. After burning, the sand is cooled for a few minutes and then weighed. The total "percentage" (p) of moisture is then calculated from the relation:

$$p=100\frac{W-W'}{W'}$$

Where W = weight of damp sample and W′ = weight of sample after drying.

Another simple method based on the same principle is to dry a sample of the damp sand in an oven or over an open fire until it has a constant weight. Knowing the weight before and after drying, the percentage of moisture may be calculated. When using either of these methods, it is necessary to know the absorption of the aggregate to determine the amount of free moisture present as only the free moisture becomes part of the mixing water.

Calculations regarding moisture content are much simplified and are made more nearly accurate if the standard measurements are made on aggregates in a surface dry condition and if the total percentage of moisture in heated samples is at once corrected by deducting the water of absorption to indicate surface moisture only.

Test for Consistency

As has been stated, a test that will indicate changes in consistency is the slump test described on page 63. The slump cone should be filled in three layers of approximately equal volume. On account of the larger diameter at the bottom, this means that for the first layer the cone should be filled to about one-fourth its height.

Frequency of Making Tests

The frequency of making tests will depend largely upon the uniformity of the aggregates. At the beginning of operations it may be advisable to make these tests two or more times a day, but as the work progresses they may be made at longer intervals. When the aggregates are uniform and are properly handled to maintain this uniformity it may be necessary to make some of the tests only at infrequent intervals. Usually moisture tests are made once or twice a day. After the inspector has made a few tests, he will be able to judge the moisture content fairly accurately and it will be necessary to make a test only when a change is apparent. The slump test is made whenever the appearance of the concrete indicates a change in consistency or as a matter of routine inspection for record.

MEASUREMENT OF MATERIAL

The proper and accurate measurement of all the ingredients used in concrete is necessary for the production of uniform batches of a given quality. Accurate measurement is also of assistance in producing the most economical results and prevents variations in the mix that would cause delay to the progress of the work.

Measuring Equipment

Selection of equipment must, of course, depend primarily upon the type and extent of the work and no general recommendations can be made regarding it. The more extensive the work and the more severe the requirements as to uniformity, the more important becomes the layout and equipment. On many jobs, if full advantage is taken of the possibilities of properly designed mixes, it would no doubt be found economical to install carefully designed equipment. Batcher plants are now very common. Since they measure aggregate by volume, proper allowance must be made for the bulking caused by the moisture.

Equipment for weighing the ingredients is also coming into use on a considerable scale. When aggregates are weighed no account need be taken of the bulking factor and the only correction necessary is for the weight of the moisture present. Even if this is neglected, the error in quantity of aggregate is slight.

The inundation method of measuring the sand and water is also used. The "inundator" is a patented device based on the principle that saturated sand has a constant volume. It consists of a tank suspended under the sand bin in which is placed enough water to inundate the sand. The sand is introduced into the water by sifting to prevent entrapping of air. The adjustable tank is set so that when completely filled with sand and water the desired amount of sand is measured. Additional water required to give the specified water-cement ratio is measured in an auxiliary tank. The feature of the inundator is that it corrects for bulking and moisture in the sand in one operation.

Another device is based on submerged weighing. Its feature is that both the sand and mixing water are weighed. Since the sand is weighed, no correction is necessary for bulking. An overflow arrangement gives automatic correction for moisture when the sand is submerged.

A patented device for measurement of cement and water now in use is the "concrete strength regulator" in which the water is balanced against the cement on the principle of a beam scale. A movable counter-weight is provided to allow for variations in the moisture content of the aggregate which, of course, must be determined from time to time as may be necessary. Bulking corrections may still be necessary with the use of this device. The feature of this device is that the workability can be immediately changed by varying the amount of cement and its balanced quantity of water without any change in aggregate quantities.

In many cases the use of new equipment has been justified even under the older practice of specifying concrete wholly on the basis of arbitrary mixes. When the newer practice of designing concrete mixtures for a given requirement comes into more general use, such plant installations will be quite common.

Where old equipment is used it should be calibrated so that the exact quantity of material measured is known. Even wheelbarrows may be measured to give more accurate results than are often obtained.

Of greatest importance is the proper control of the mixing water. The whole intent and purpose of designing a mixture by the water-cement ratio strength law will be lost if the necessary precautions are not taken to maintain, throughout the duration of a job, the accurate measurement of the water. Improvements have been made in water tanks and many concrete mixers are now equipped with measuring devices which give satisfactory results when properly used. Some of these consist of a movable pipe inside the tank which acts as a siphon. When the tank has been discharged to the proper level the siphon is broken, thus shutting off the flow to the mixer and automatically measuring the desired quantity. Some tanks are equipped with adjustable discharge pipes, while others have meters or gauges. On some installations, the water measuring tank has been installed independent of the mixer and the contractor has used a measuring device of his own design. In a few cases the water has been weighed. The leakage of water into the mixer before or after the tank has been discharged should not be permitted. The measuring device should be calibrated to give accurate quantities and adjustments should be made quickly, but the device should be locked so that it may be adjusted only by the man designated by the engineer.

MIXING CONCRETE

Practically all concrete even for small jobs is mixed by machine in batch mixers of various capacities, from two to thirty cubic feet of concrete per batch. Mixers have been brought to a high state of efficiency, producing satisfactory results at a minimum cost of labor and power. Small changes in the speed of the mixer have little effect on the

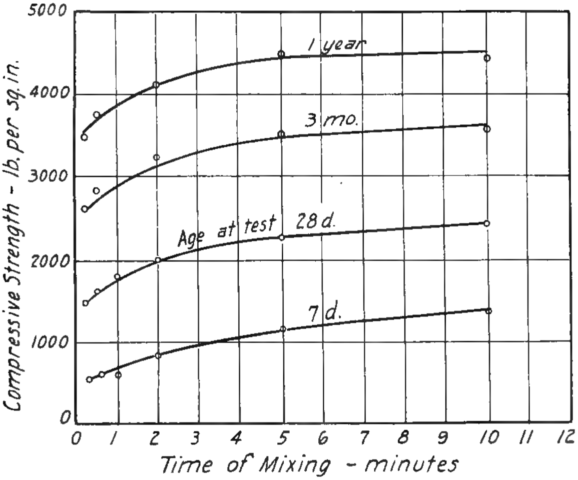


Fig. 2
Typical relation between time of mixing and the compressive strength of concrete.

strength of the concrete, as it is largely the time element of mixing and not the rate of rotation of the mixer that influences the strength and quality. The mixer should never be overloaded above the rated capacity as such overloads prevent thorough mixing. If increased output is needed it should be obtained by a larger mixer or by additional mixers rather than by speeding up or overloading the equipment on hand.

Tests show that the strength of concrete is increased by longer periods of mixing. Typical values from these tests are shown in Fig. 2. The rapid increase in strength for different periods of mixing up to about two minutes can be seen on this curve. For instance, concrete of the usual quality mixed for that period is from 20 to 35 per cent stronger than concrete mixed only 15 seconds.

In the tests from which these curves were constructed it was found that thorough mixing also makes for more uniform concrete. Specimens made of concrete mixed for only 15 seconds showed an average variation of individual specimens of about 30 per cent from the average strength, while specimens made of concrete mixed for two minutes varied less than 10 per cent. Furthermore, thorough mixing gives increased workability, which in turn requires less labor in placing or permits the use of slightly larger quantities of aggregate with a given quantity of cement and water in their fixed ratio. A still further advantage of thorough mixing is that it is of great assistance in securing watertight concrete. The effective time of mixing is from the time all of the materials, including the water, are in the mixer. The mixing should be continued for at least one minute.

For concrete where waterproof construction is an essential or where the structure is to be exposed to severe weather conditions a period of mixing somewhat greater than is customary will be found to be desirable. In some lines of work if the test of quality of the finished product is introduced it will likely be found that one of the economical methods of producing the desired quality will be through longer time of mixing.

Many mixers are now equipped with time locking devices. When these are set the mixer cannot be discharged until the allotted time has elapsed. Only the man in charge of the work should have access to the setting of these devices.

The initial set of cement does not ordinarily take place within 2 or 3 hours after it has been mixed with water. Mixed concrete that is left standing will dry out to some extent but may be used provided it is still plastic. The addition of water to make the mixture more workable should not be allowed, as this lowers the strength. Concrete that has partially set should not be placed in the forms.

TRANSPORTING CONCRETE

As in the case of measuring equipment, selection of means of transporting from the mixer to place of deposit is primarily a question of economy, the only qualification being that the means selected must not interfere with the delivery at the place of deposit of concrete of the proper quality and uniformity. The design of the mix may be governed largely by the type of equipment to be used in transporting concrete.

If chuting equipment is to be used, the slope and length of the chute may be adjusted to permit the movement of the desired mix or the mix may be adjusted to fit the slope of the chute, maintaining, of course, the desired water-cement ratio. The workability of the concrete, the character of the materials used and the design of the chutes will determine the slope of chutes that will be required. It is recommended that the combination of these factors allow a slope not flatter than 1 to 3 nor steeper than 1 to 2. The mix should be designed so that the concrete will travel fast enough to keep the chutes clean but it is not desirable or necessary to have it move so fast that the materials will segregate. The cycle of operations should be so timed that a nearly continuous flow of concrete is obtained at the discharge end of the chute. When long chutes are used the concrete should be delivered into a hopper, preferably of the bottom gate type, before it is deposited into the forms. In this way some remixing action is given to correct any segregation which may have taken place. If concrete is placed directly in the forms, it must not fall freely more than a few feet nor be shot out at an angle. At no point in the cycle of operations should water be added to the mix after the concrete has left the mixer, and, when the chutes are flushed with water, care should be taken that this water does not enter the forms.

Even with transportation in buggies or wheelbarrows some consideration must be given to the mixture in order that segregation does not take place in handling over the rough runways. Central mixing plants with long distance hauls either in trucks or cars likewise impose certain restrictions. A rather dry consistency is usually required to prevent segregation. Concrete transported in this way should not be placed directly in the forms but should be dumped into a hopper and rehandled into the work.

PLACING CONCRETE

No element in the entire cycle of concrete production requires more care than the final operation of placing concrete at the ultimate point of deposit. Before placing concrete, all debris and ice should be removed from the places to be occupied by the concrete and the forms should be thoroughly wetted (except in freezing weather) or oiled. Temporary openings should be provided where necessary to facilitate cleaning and inspection immediately before depositing concrete. These should be so placed that excess water used in flushing the forms may be drained out.

Prevention of Segregation

With a well-designed mixture delivered with proper consistency and without segregation, placing of concrete is greatly simplified; but even in this case care must be exercised to further prevent segregation and to see that the material flows properly into the corners and angles of forms and around the reinforcement. Constant supervision is essential to insure such complete filling of the form and to prevent the rather common practice of depositing continuously at one point, allowing the material to flow to distant points. Flowing over long distances will cause segregation especially of the water and fines from the rest of the mass. An excessive amount of tamping or puddling in the forms will also cause the materials to separate. When the concrete is properly proportioned the entrained air will escape and the mass will be thoroughly consolidated with very little puddling. Light spading of the concrete next to the forms will prevent honeycombing and make surface finishing easier.

In placing concrete in deep layers a gradual increase in the water content of the upper portion is quite certain to result from the increased pressure on the lower portions. The excess water should be worked to a low point, without actually causing a flow, and removed. It should be remembered that excess water in the upper layer is just as objectionable as excess mixing water.

Prevention of Laitance

Attention is called to the significance of a layer of laitance on a section of concrete. It has been a common assumption that if this laitance is completely removed all danger has been eliminated; in fact, specifications frequently place considerable stress on its removal. Laitance, however, can only form from the presence of excess water, which means that the upper portion of the concrete will be porous, and the removal of a small layer of laitance still leaves several inches of porous concrete through which water will pass even under moderate pressure. The effect of this porous layer at the top of each day's work can be seen in many structures subject to water pressure. The lower portion of the layer is found to be hard and dense while the upper portion shows efflorescence due to passage of water.

FINISHING CONCRETE

Many methods of finishing concrete surfaces are in use, such as troweling, tooling, cleaning or stuccoing. These methods cannot be described here, but a precaution regarding troweling may not be out of place. Too much troweling, while the concrete is still plastic, should be avoided as the cement and other fine materials are brought to the surface, causing surface cracks or checking. Only sufficient troweling should be done to give an even surface. Then when the concrete has taken its initial set it may be troweled again to produce a hard, dense, smooth surface.

The practice of sprinkling dry cement on floors or sidewalks to take up surface water is to be condemned. Such cement forms a rich layer of fine material on the surface and is almost certain to result in checking. Surface water should be avoided in the first place or should be allowed to evaporate before finishing.

CURING CONCRETE

Concrete hardens because of chemical reactions between portland cement and water. The process continues indefinitely, so long as the temperatures are favorable and moisture is present to complete the hydration. The quality of concrete, therefore, is dependent on its age and the conditions under which it cures.

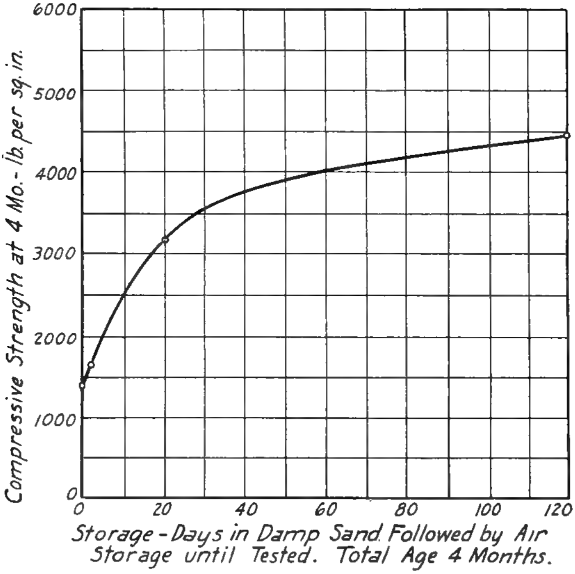


Fig. 3

Typical relation between curing condition and the compressive strength of concrete. Specimens were cured in damp sand for the period indicated in horizontal scale, followed by air storage until time of test.

Effect of Moisture

Fig. 3 gives a summary of the results of a series of tests, showing that moist curing during the early hardening period greatly increases the strength. In these tests all the specimens were tested at the age of four months but they were cured in damp sand for various periods and then allowed to cure in dry air until tested. It will be seen from Fig. 3 that an increase in strength of 72 per cent was obtained by keeping the concrete damp the first ten

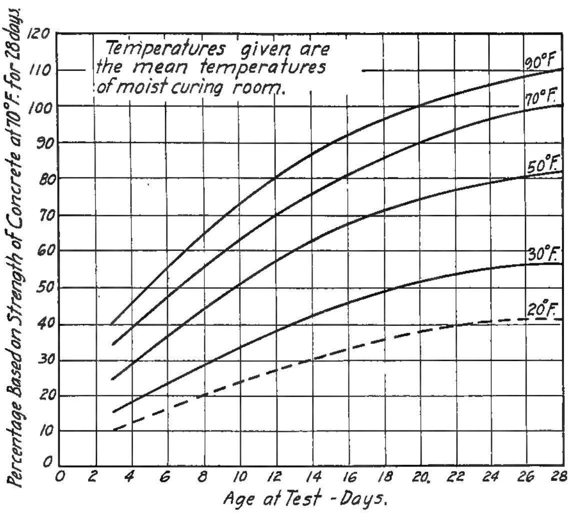


Fig. 4

Effect of temperature during curing period on the compressive strength of concrete. Data taken from Bulletin No. 81, Engineering Experiment Station, University of Illinois.

days instead of letting it dry out. Keeping the concrete damp three weeks increased the strength 124 per cent and for four months 207 per cent over the strength of concrete cured the entire period in a dry atmosphere and being cured only by the water in the specimen before it evaporated.

Effect of Temperature

The effect of temperature on the rate at which the hardening of concrete proceeds is brought out very clearly by tests reported in Bulletin 81 of the Engineering Experiment Station, University of Illinois. Fig. 4 shows how the strength is affected by the temperature. It will be seen from this chart that concrete allowed to harden at a temperature near freezing has considerably lower strength than concrete cured in a temperature of 70 degrees Fahrenheit.

Effect of Age

The strength of concrete, under favorable curing conditions, increases with age. This increase is very rapid in the early ages but continues more slowly for an indefinite period. Tests that have been made at various ages up to five

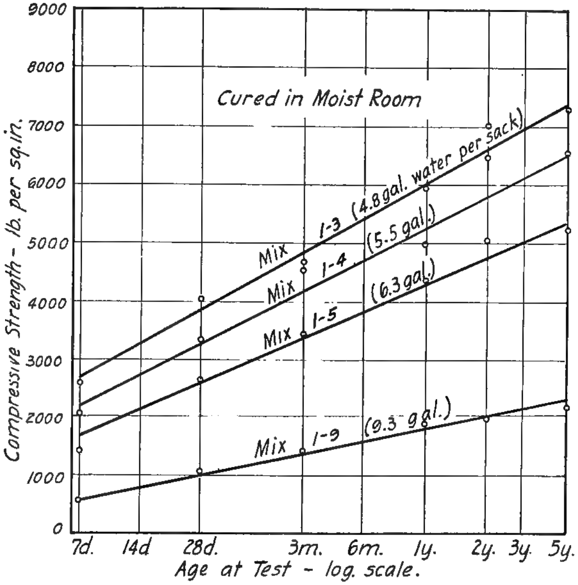


Fig. 5

Increase in strength of concrete with age. Moist curing.

years on concrete cured in a moist atmosphere are illustrated in Fig. 5. Note that the increase from 7 to 28 days is about equal to the increase from 6 months to 2 years. The strength of concrete at 28 days is now commonly taken as a standard for comparison.

Curing Increases Watertightness and Wear Resistance

Of perhaps greater importance than the effect of proper curing on strength is its effect on other qualities of concrete. Thorough curing is one of the most important elements in the production of watertight concrete. Building up the internal structure of the concrete through more complete hydration of the cement is one of the most effective and economical means of making it impervious to water. The necessity for proper curing of retaining walls, tanks and other concrete subject to hydrostatic pressure or severe weather conditions cannot be overestimated.

The resistance to abrasive action is increased in a similar manner, showing the importance of curing floors, pavements and other surfaces subject to such wear. Continuous damp curing, *particularly in the early stages of hardening*, aids in securing a hard, dense surface and in preventing checking and dusting. The moisture should be applied soon enough to prevent the surface from drying out and shrinking before the concrete has hardened.

Methods of Curing

Practically all concrete as mixed contains an excess of water over that required for hydration. The problem of curing, therefore, is essentially to prevent the evaporation of this water. In some cases the surface of the concrete is sealed with a compound applied immediately after it has set. This is effective where sealing of the surface without penetration is accomplished. Wet burlap, canvas, or straw coverings are often used with good results. The covering should be placed as soon as it can be done without marring the surface of the concrete and care should be taken to keep the covering continuously wet by frequent sprinkling. Since fresh concrete will not take up additional water, the concrete may be wetted down immediately after finishing, taking care to prevent surface cement from being washed out. Floor finishes and all two-course work should receive careful attention as moisture is not only lost by evaporation but also some of the water from the finish layer is drawn out by the base course. Ponding is a good method of curing for flat horizontal surfaces, such as floors and pavements. With this method the surface to be cured is surrounded with small earthen dikes and then kept flooded with water for the desired period. Vertical surfaces are more difficult to cure but the effort is well worth while. They may be protected by leaving the forms in place as long as possible, or by hanging canvas or burlap over the surface and sprinkling. Exposed surfaces should be protected from drying out for at least 7 days, and for a longer period when practicable.

Protection in Cold Weather

The studies on the effect of temperature on the hardening of concrete show that at the lower temperatures the process practically ceases. In cold weather work it is important to protect the concrete from freezing and maintain it at a temperature where it can harden properly. It should be kept at a temperature above 50° F. for four or five days if possible and in no case less than 72 hours. This is usually accomplished by heating the aggregates and water before the concrete is mixed, covering the concrete, and heating with salamanders or steam. When heat is provided, care should be taken to keep the air from drying out. Canvas enclosures heated with live steam are often used in the construction of concrete buildings and provide excellent curing conditions since moisture as well as heat is present. Accelerators are sometimes used to reduce the necessary time of protection. (See page 41.) Anti-freezing compounds are of doubtful value.*

FOLLOW-UP TESTS

Follow-up tests to determine the effectiveness of the field control methods may be included in the schedule of tests. These tests should include some specimens from each day's operation, also a sufficient number of specimens during an occasional day's operation to determine the daily variation. After the work has been well organized and the quality of the concrete being produced is established by these tests, the number of specimens and the frequency at which they are taken may be greatly reduced. On long jobs with constant weather conditions after the work is well in hand, only a few tests during the week may be necessary. At the approach of cold weather, it is especially important that the test program be such that a full knowledge of the quality of concrete is available at every stage of the construction.

Where the water-cement ratios are selected from Curve A of Fig. 1, at least one specimen should be tested for each 100 cu. yd. of each class of concrete being placed. Where the water-cement ratios are to be established by tests, at least one specimen should be tested for each 50 cu. yd. of concrete of any one strength and not less than two specimens of each strength of concrete for any one day's operation.

The generally accepted test for strength of concrete is the compression test, using cylinders of height twice the diameter (usually six inches in diameter and twelve inches high). The beam test is also coming into extensive use as a test of the quality of concrete pavement. In some cases cores are taken from the completed structure and tested to compare with the cylinders made during the course of construction. Such cores should be obtained by following the Standard Methods of Securing Specimens of Hardened Concrete from the Structure (Serial Designation C 42-27) given on page 67, including the provision for saturating the specimen for 48 hours before test. Corrections are made to the basis of a specimen of standard size, and to the standard age of 28 days.

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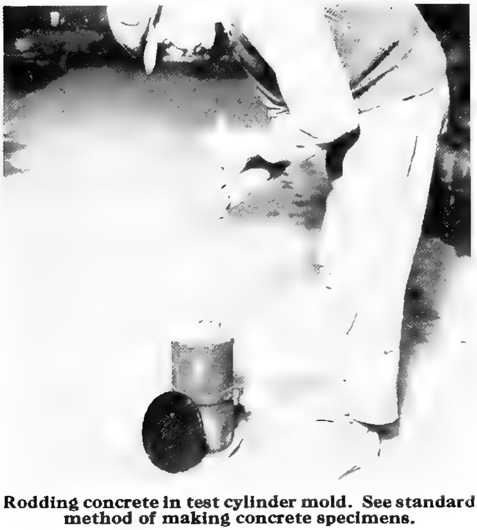
*The Portland Cement Association will furnish specifications for cold weather concreting on request.

Method of Making Test Specimens

The test cylinders should be made in accordance with the Standard Methods of Making and Storing Specimens of Concrete in the Field given on page 65. Every precaution should be taken to follow the standard practice. When forms without a bottom are used, they should be heavy enough to stand firmly on the steel plate used as a base to make a tight joint which will prevent leakage. Light forms will have a tendency to rise slightly as the concrete is rodded, allowing water to escape at the bottom. When cardboard forms are used, they should be of the type having a cardboard bottom glued to the form. Immediately after casting, the top of the cylinder should be covered to prevent evaporation. A layer of water on top of the specimen is an indication of nonworkability and the concrete in the structure should be examined for segregation.

Curing Test Specimens

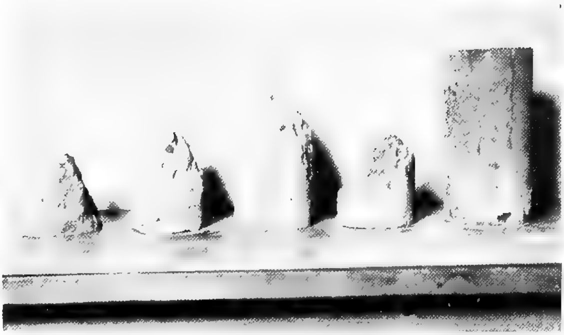
The adoption of proper curing methods for the specimens, especially in cold weather, is important on account of the effect of temperature. Cylinders may be cured on the work or under uniform temperature in a moist room, such as is used in a laboratory. The laboratory curing gives more accurately an indication of the potential quality of the concrete. The field-cured specimens may give a more accurate interpretation of the actual strength in the structure but they offer no explanation as to whether any insufficiency in strength is due to error in proportioning, poor materials or unfavorable curing conditions. The best method, it would seem, therefore, would be to make tests of both field and laboratory-stored specimens, especially when the weather is unfavorable, in order that the tests may be properly interpreted. The laboratory specimens should be damp-cured at normal room temperature of about 70 degrees Fahrenheit.



Rodding concrete in test cylinder mold. See standard method of making concrete specimens.

Capping Test Specimens

The requirements of the standard methods for capping specimens should always

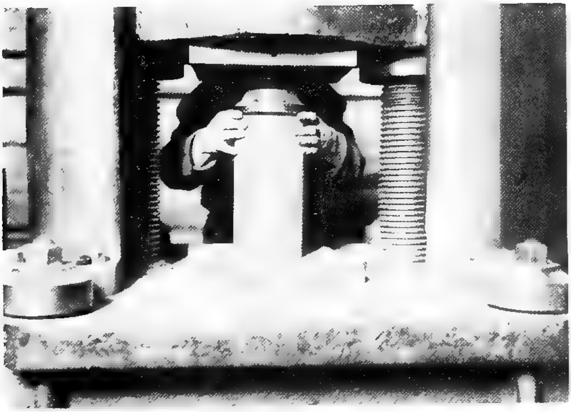


Typical breaks of concrete test cylinders.

be observed as the end condition of the cylinders has an important influence on the test results. For example, tests on cylinders with a convexity of 0.01 in. give results from twenty to thirty-five per cent lower than cylinders having plane ends as splitting of the specimen occurs instead of true compression. Troweling the top of cylinders or pressing down the concrete with a steel plate is not sufficient as the shrinkage will be uneven. Capping the cylinders after shrinkage has taken place is the only satisfactory method. When using cardboard forms with cardboard bottoms, both ends of the cylinders should be capped. This may be done after the cylinder reaches the laboratory. The cement paste used in capping should be allowed to stand for an hour or two before using so that most of the shrinkage will have taken place. When this is done, the cap will not shrink away from the concrete cylinder.

Testing the Specimens

In making the compression test on the concrete cylinders, the procedure given in the Standard Methods of Making Compression Tests of Concrete on page 68 should be followed. The specimens should be carefully measured to determine the average diameter. This is especially important where the specimen was made in a cardboard form. An adjustable bearing block should be used as cushioning materials do not accomplish the same results. Tests on cylinders using cushioning materials show results as much as fifty per cent lower than when a bearing block is used. In general, only the ulti-



Placing test cylinder for testing. Note spherical bearing block on machine head.

Capping test cylinder. See standard method of making concrete specimens.

mate compressive strength need be observed. The load indicated by the testing machine at failure of the test should be recorded and the unit compressive strength calculated in pounds per square inch, the cross-sectional area having been computed from the average diameter of the specimen.

An important factor in the testing of concrete is the moisture content of the specimen. A saturated specimen will show a strength twenty to thirty per cent less than when tested dry. This is of special importance when comparing cores cut from a road slab or structure with specimens made at the time of mixing, as the standard procedure is for the latter to be tested just as they are taken from the moist room or wet sand.

Relation of 28-Day and 7-Day Tests

Test specimens are generally tested when twenty-eight days old and this has come to be regarded as the standard age. When the time element is important and it is not practicable to wait for the 28-day tests, some of the specimens may be tested at 7 days and approximate values for the 28-day strength may then be calculated from the equation: $S_{28} = S_7 + 30\sqrt{S_7}$, in which S_7 and S_{28} are the compressive strengths at 7 and 28 days respectively. However, this formula is not accurate for all materials and in cases of doubt or where the calculated value is less than the specified strength at 28 days it is advisable to either wait for the 28-day tests before proceeding or make the necessary adjustments in the mix to produce the desired strength.

SPECIAL PROCESSES AND MATERIALS

WATERTIGHT CONCRETE

Watertight concrete can be made with portland cement without special materials by following the few simple directions given here. Furthermore, watertight concrete cannot be made if these directions are not followed, regardless of what special materials may be used. These facts are demonstrated by the excellent results obtained with portland cement concrete in numerous structures where correct methods of construction have been followed.

The essential requirements for watertight concrete are:

Sound aggregates of low porosity.
Limited amount of mixing water.
Plastic, workable mixtures.
Thorough mixing.
Proper placing.
Favorable curing conditions.

These factors have been discussed and they are repeated here only to emphasize their importance in securing the desired results. It is easily seen that to resist the passage of water both the aggregate and the cement paste must be resistant. This requires sound aggregates of low porosity. These are widely distributed and most of the commercial materials meet this requirement. The amount of mixing water should not exceed about 6 gallons per sack of cement for thin sections. Experience has shown that when the concrete is in large masses, water-cement ratios up to 7 gallons per sack of cement give ample watertightness. This amount includes the free moisture in the aggregates for which the proper correction must be made.

A plastic, workable mix is necessary so that the concrete can be thoroughly compacted to fill the forms without separation of the materials. Thorough mixing not only gives more uniform batches but increases the plasticity, thus facilitating placing. The concrete should be transported and placed without segregation of the materials. The accumulation of undue water on the surface should be avoided and all laitance removed. In deep layers the accumulation of water may be avoided by using drier batches near the top of the layer. Placing should be continuous wherever possible. When interruptions cannot be avoided, every precaution is necessary to obtain a good bond with the hardened concrete.

Favorable curing conditions are very important in the production of watertight concrete. The concrete should be kept wet for a period of two weeks and longer when practicable. In cold weather the concrete should be protected from low temperatures. Tanks and reservoirs should not be filled until after the curing period.

In structures that are intended to be watertight, but where unequal settlement may be expected, it is necessary to provide a flexible waterproof membrane. Such a membrane acts as a seal to prevent leakage through cracks which may result from the settlement.

HIGH EARLY STRENGTH CONCRETE

It is often desirable to produce concrete having comparatively high strength a few days after it has been placed so that it can be put into use at the earliest possible moment. High early strength concrete can be made with standard portland cement. Since the important factors

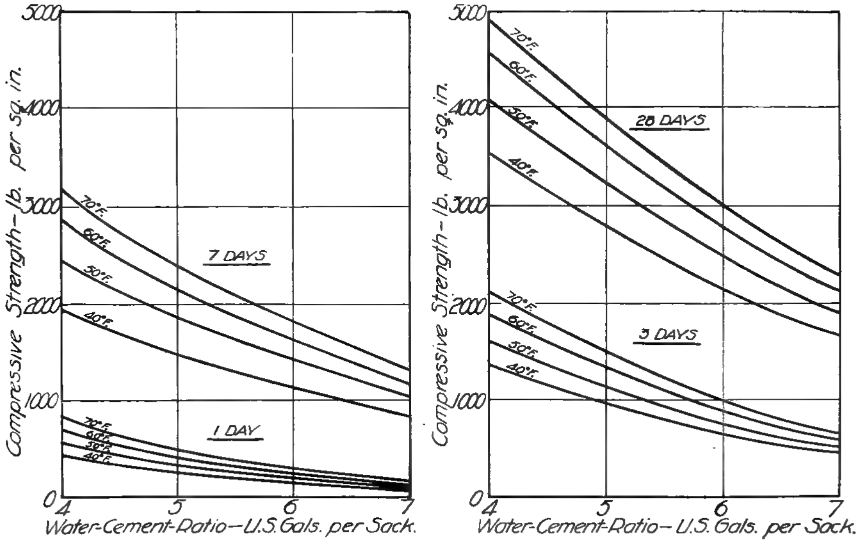


Fig. 6

Effect of age and temperature on the strength of concrete of various water-cement ratios.

which govern the strength of portland cement concrete are the relative proportions of cement and mixing water, time of mixing and conditions during curing, these factors may be adjusted to produce concrete of the desired strength at an early age. Sometimes an accelerating admixture may be used to further increase the rate at which the concrete develops its early strength.

Fig. 6 shows the relation between the compressive strength of concrete when cured damp and the water-cement ratio for 4 ages and different temperatures of curing. The data for 70 degrees Fahrenheit are based on Portland Cement Association laboratory results, using average materials and following standard methods of test of the American Society for Testing Materials. The data for the other temperatures were deduced from these by using the data presented in Fig. 4.

The diagram shows that if 2000 lb. concrete is required at 3 days, it can be secured by using 4¼ gallons of mixing water per sack of cement and curing at 70 degrees Fahrenheit. Correspondingly lower water-cement ratios are required for lower curing temperatures. For example, if 1000 lb. concrete is required at 3 days, it may be secured by using 6 gallons of water per sack of cement and curing at 70 degrees Fahrenheit, but if the curing temperature is only 40 degrees the mixing water must be less than 5 gallons. These lower water-cement ratios require more cement to produce concrete of a given consistency or condition of workability.

Increasing the time of mixing will increase the strength and also produce a more homogeneous mixture of better workability. For concrete cured at normal temperature, increasing the mixing time from 1 to 2 minutes will add about 100 pounds per square inch to the strength at 3 days and about 200 pounds per square inch may be added by increasing the mixing time from 1 to 5 minutes.

Accelerators

The accelerating admixtures that are most generally used are calcium chloride and calcium oxychloride. These accelerators do not react the same with all portland cements and preliminary tests should be made using the brands of cement and admixture selected for the job before proceeding with important work. The quantities of admixture should not exceed from 2 to 4 per cent of calcium chloride or 7 to 10 per cent of calcium oxychloride by weight of the cement and usually these quantities are the most effective.

The admixture should be dissolved in the mixing water before adding to the mixer. Most contractors make up a solution of known concentration, adding the desired amount to each batch. Thus, if he desires to use 2 lb. of calcium chloride per sack of cement, he may make up a solution containing 1 lb. per quart and will then add 2 quarts of the solution for each bag of cement in the batch. This must be regarded as part of the mixing water.

CYCLOPEAN CONCRETE

Large field stones or cobblestones are sometimes embedded in the concrete for use in massive structures such as foundations, dams, piers and retaining walls. This is known as cyclopean concrete. Its use is decreasing as the extra labor and equipment required for properly handling and placing the stones is often more than the saving in materials. Since rubble concrete is placed in large open forms, a rather stiff concrete can be placed. Sufficient equipment must be on hand so that the stones may be placed without delaying the concreting process, or construction joints will be formed when the concreting is stopped to place the stones. The stones should be sound and clean and each stone completely surrounded by concrete. The large stones should not lie nearer to each other or to an exposed surface than 6 inches.

CONCRETE PRODUCTS

Concrete block, brick, tile and other products are made by tamping the concrete into steel molds by machinery. The mixture must be so dry that when the mold is removed, immediately after the tamping process, the concrete will retain the shape of the mold. Such concrete in itself is not of a workable consistency and hence the water-cement ratio principle does not apply. The equivalent of workability is supplied by mechanical tamping. Sufficient water should be used so that the tamping will compact the concrete. The concrete must be thoroughly wet cured to maintain the moisture necessary for complete hydration, making a strong, dense and impermeable unit.

PLACING CONCRETE UNDER WATER

Concrete should not be deposited under water if practicable to deposit in air as there is always some uncertainty as to the results obtained from placing under water. The additional expense and delay of avoiding this method will be nearly always warranted. Where conditions are such that concrete must be placed through water, expert supervision is necessary and every precaution must be taken to prevent the cement from being washed out of the concrete. The formation of laitance on top of the concrete should be avoided. When it is impossible to avoid, it should be removed. A fairly rich mix, containing at least 7 sacks of cement per cubic yard of concrete, should be used.

One successful method of placing concrete under water has been with the tremie. The tremie is usually a steel pipe or tube long enough so that the lower end will reach the bottom of the work when the upper end is above water level. A hopper is usually provided at the upper end to receive the concrete. When placing operations are to start, the lower end of the tremie is plugged to prevent the entrance of water or the escape of concrete. The tremie is filled with concrete and lowered into position. When the lower end reaches the bottom of the work, the plug is removed and the concrete allowed to flow out slowly. As concreting proceeds the lower end should be kept submerged in the concrete for several feet and the tremie kept constantly full of concrete.

Drop bottom buckets are also used for placing under water. The bucket should be of a type that cannot be dumped until it rests on the surface upon which the concrete is to be deposited. The bucket should be completely filled and slowly lowered to avoid back-wash. When discharged, the bucket should be withdrawn slowly until well above the concrete. The concrete that is in place should be disturbed as little as possible.

LIGHT WEIGHT CONCRETE

By using aggregates of light weight, the weight of concrete may be reduced considerably. Light weight concrete is desirable for roof slabs, partitions, floor fills, fireproofing, masonry units and other purposes. Cinders are often used as aggregate in concrete floor fills and in masonry units on account of their light weight. Light weight aggregates made from burnt clays are now available in many localities. Mineralized sawdust or shavings have been used in some cases. Where these materials are to be used in concrete that is to carry load, tests should be made to determine the combination of materials necessary to produce the required strength.

Patented methods of aerating the concrete are in use to some extent. For this process finely divided chemicals which generate gases are added to ordinary concrete, causing it to fluff up so that upon hardening it is full of air spaces.

Concrete having weight as low as 50 lb. per cu. ft. may be made by aerating. Burnt-clay aggregate concrete weighs about 100 lb., cinder concrete about 120 lb. and slag concrete about 130 lb. per cu. ft. Ordinary concrete weighs about 145 lb. per cu. ft.

COLORED CONCRETE

Colored aggregates or color pigments may be used in concrete to give it a wide range of tints. Only mineral pigments should be used. On account of a tendency to reduce the strength the amount should be limited to 10 per cent, but, generally, the amount required is not over 5 per cent by weight of the cement. The pigment should be thoroughly mixed with the cement before adding the other ingredients so that it will be evenly distributed throughout the mixture. To prevent variations in tint the cement and pigments should be weighed for each batch. In determining the amount of pigment for a certain tint, preliminary tests are advisable, allowing the concrete to dry as it is considerably darker when wet than when dry.

SHRINKAGE AND EXPANSION OF CONCRETE

Concrete changes somewhat in volume with different conditions of exposure. Shrinkage takes place from the time of casting and continues for a period of several months upon exposure to dry air conditions. After concrete has hardened it will swell slightly when immersed in water. When drying is resumed, shrinkage again takes place to about the same extent as though no moist curing had intervened. Volume changes are also caused by temperature changes, higher temperatures causing it to expand and lower temperatures to contract. Although affected by several factors, the volume change in concrete from wetting or drying may be roughly stated as about equivalent to that resulting from a temperature change of 100° Fahrenheit.

The effect of different factors causing volume changes is important because of their effect on the behavior of concrete structures exposed to different conditions. Thus volume changes should be reduced to a minimum to prevent checking of the surface and internal stresses caused by undue amounts of shrinkage or expansion.

The fundamental cause of shrinkage is the loss of water resulting from evaporation or from absorption by the aggregate particles or by the forms. It is convenient to consider shrinkage as taking place in two stages, the first while the mass is plastic and the second during the later period of hardening after the member has assumed a definite structural form.

Shrinkage during the first stage is quite rapid, the rate depending upon the rate of evaporation which, in turn, is affected by the humidity conditions, air currents and the size and shape of the mass. In a small thin section of mortar or concrete exposed to drying conditions, a great deal of shrinkage at this time will result in checking. This can be avoided by preventing the loss of water from the mass either through surface evaporation or by absorption by the aggregates, subgrade or forms.

When water is to be extracted from the mixture during the early stage, a process sometimes used to decrease the effective water-cement ratio, it should be accomplished quickly while the mass is still plastic and should be accompanied by a working of the mass to effect a complete consolidation.

Shrinkage during the second stage, which is very much slower than during the first stage, is also due to loss of water from the concrete. Surface cracks are sometimes caused by too rapid drying out, causing the surface to shrink more rapidly than the interior of the concrete. This can be prevented by early curing and extending the curing period so that the shrinkage will take place more uniformly and the concrete will have sufficient strength to overcome any strains which may be set up.

Since the cement paste is the material which is principally responsible for the volume changes, it follows that the greater the cement content the greater will be the shrinkage or expansion. Other factors, however, also influence these changes. The wetter the mix, that is, the higher the water-cement ratio, the greater will be the shrinkage.

In mortars a difference in the proportions of cement to sand does not cause as great a difference as is commonly supposed. This is because the richer mortars, while containing more cement, require less water to give a definite consistency and the tendency to shrink due to the large cement content is partially offset by the lack of tendency to shrink because of the small water content. In concrete the same conditions apply, the chief difference being that the larger size of aggregate particle reduces the amount of paste in a unit volume of the mass and therefore reduces the amount of shrinkage.

Large structures are provided with joints to allow for the volume changes. Structures presenting a large area to a wide range of weathering conditions, such as pavements and sidewalks, require joints at frequent intervals. Each structure is a problem in itself and good judgment is necessary in the application of the empirical rules sometimes used in determining the spacing of joints.

SPECIFICATIONS FOR PLAIN AND REINFORCED CONCRETE

Water-Cement Ratio Method

It is not enough that the engineer himself be thoroughly informed concerning the essentials of concrete construction. He must in addition specify the requirements for his structures in such a way that in the normal execution of the contract these requirements are effectively carried out. The following specification has been drawn to make possible the application to a particular structure of the principles brought out in the preceding chapters of this booklet for the proper design and control of the concrete.

The essential feature of this specification is the specification of quality on the basis of the water-cement ratio and proper workability. By leaving to the contractor considerable leeway in the selection of his materials, proportions and consistency and at the same time fixing the water-cement ratio and workability a situation is created whereby the interests of the contractor and the owner are to an unusual degree identical. This situation eliminates friction and creates an atmosphere of mutual understanding that encourages full compliance with the specification and insures concrete of the desired quality.

Specifications based on the water-cement ratio method have been used in a large number of structures. The results obtained from their use have been satisfactory in every respect alike to the architect, owner and contractor. Similar specifications have become standard practice of many engineers, architects, railroads and other public utilities, and large industrial concerns. Municipalities are also recognizing the advantages of the water-cement ratio method and are rapidly modernizing their building codes to require control of concrete quality by this method. As a result it has become practicable to use higher stresses in design, thus using concrete more efficiently.

SPECIFICATIONS FOR PLAIN AND REINFORCED CONCRETE

Water-Cement Ratio Method

These specifications are based on the Proposed Standard Building Regulations submitted by Committee E-1 of the American Concrete Institute, 1928.

MATERIALS

1. Portland Cement

(a) Portland cement shall conform to the "Standard Specifications and Tests for Portland Cement" (Serial Designation: C9-26) of the American Society for Testing Materials.

2. Concrete Aggregates

(a) Concrete aggregates shall consist of natural sands and gravels, crushed rock, crushed air-cooled blast furnace slag, or other inert materials having clean, uncoated grains of strong and durable minerals. Aggregates containing soft, friable, thin, flaky, elongated, or laminated particles totaling more than 3 per cent, or containing shale in excess of 1½ per cent, or silt and crusher dust finer than the No. 100 standard sieve in excess of 2 per cent, shall not be used. These percentages shall be based on the weight of the combined aggregate as used in the concrete. When all three groups of these deleterious substances are present in the aggregates, the combined amounts shall not exceed 5 per cent by weight of the combined aggregate.

(b) Aggregates shall not contain strong alkali or organic material which gives a color darker than the standard color when tested in accordance with the "Standard Method of Test for Organic Impurities in Sands for Concrete" (Serial Designation: C40-27) of the American Society for Testing Materials.

(c) The maximum size of the aggregate shall be not larger than one-fifth of the narrowest dimension between forms of the member for which the concrete is to be used nor larger than three-fourths of the minimum clear spacing between reinforcing bars. By maximum size of aggregate is meant the clear space between the sides of the smallest square opening through which 95 per cent by weight of the material can be passed.

3. Water

(a) Water used in mixing concrete shall be clean, and free from strong acids, alkalis, oil, or organic materials.

4. Metal Reinforcement

(a) Metal reinforcement shall conform to the requirements of the "Standard Specifications for Billet-Steel Concrete Reinforcement Bars" of Intermediate Grade (Serial Designation: A15-14), or for "Rail-Steel Concrete Reinforcement Bars" (Serial Designation: A16-14) of the American Society for Testing Materials. The provision in these specifications for machining deformed bars before testing shall be eliminated.

(b) Wire for concrete reinforcement shall conform to the requirements of the "Tentative Specifications for Cold-Drawn Steel Wire for Concrete Reinforcement" (Serial Designation: A82-27) of the American Society for Testing Materials.

(c) Structural steel shall conform to the requirements of the "Standard Specifications for Structural Steel for Buildings" (Serial Designation: A9-24) of the American Society for Testing Materials.

(d) Cast-iron sections for composite or combination columns shall conform to "Standard Specifications for Cast-Iron Pipe and Special Castings" (Serial Designation: A44-04) of the American Society for Testing Materials.

5. Storage of Materials

(a) Cement and aggregates shall be stored at the work in a manner to prevent deterioration or the intrusion of foreign matter. Any material which has deteriorated or has been damaged shall be immediately and completely removed from the work.

CONCRETE QUALITY AND PROPORTIONING

6. Concrete Quality

(a) The working stresses for the design of this structure are based upon the minimum ultimate 28-day strength of the concrete to be used. The strength of concrete for which all parts of the structure were designed is shown on the several plans. The strength of concrete shall be fixed in terms of the water-cement ratio in accordance with one of the following methods:

(1) By established results for average materials, as provided in Sec. 7.

(2) By specific test of materials for the structure, as provided in Sec. 8.

(b) By the water-cement ratio is meant the net quantity of water in the concrete mixture, including the surface water carried by the aggregate, expressed in terms of the quantity of cement. The water-cement ratio shall be expressed in U. S. gallons per sack (94 lb. net) of cement.

7. *Water-Cement Ratio for Average Materials*

(a) Where no preliminary tests of the materials to be used are made, the water-cement ratios shall not exceed the values in the following table.

ASSUMED STRENGTH OF CONCRETE

Water-Cement Ratio[1] U. S. Gallons Per Sack of Cement (94 Lb. Net)	Assumed Compressive Strength[2] at 28 Days in Pounds Per Square Inch
4	5000
5	3750
6	3000
6¾	2500
7½	2000
8¼	1500

[1] Surface water contained in the aggregate must be included as part of the mixing water in computing the water-cement ratio.

[2] The strengths indicated are for average materials, thoroughly mixed, and concrete moisture-cured at normal temperature of 70° F., tested damp.

(b) During the progress of the work, a reasonable number of compression tests shall be made as may be required by the architect, but at least one specimen shall be tested for each 100 cu. yd. of concrete being placed. The tests shall be made in accordance with the provisions for making field tests of concrete, as provided in Sec. 9.

(c) Should the average 28-day strength of the control cylinders cured moist at 70° F. fall below the minimum ultimate strength called for on the plans, the architect shall have the right to change the water-cement ratio. In the event that the architect finds it necessary to change the water-cement ratios from those specified, adjustment, covering amount of cement and aggregates affected, will be made as an extra or a credit under the provisions of the contract.

(d) Should the average strengths shown by the cylinders cured on the job and tested subsequent to 28 days fall below the required strength, the architect shall have the right to require conditions of temperature and moisture necessary to secure the required strength.

8. *Water-Cement Ratio by Tests of Materials*

(a) Where the water-cement ratios for the various strengths of concrete are to be established by test, these tests shall be made in advance of the beginning of operations, using the materials proposed and consistencies suitable for the work and in accordance with the "Standard Method of Making Compression Tests of Concrete" (Serial Designation: C39-27) of the American Society for Testing Materials, including the provisions for curing in a moist room at 70° F. and testing wet. A curve representing the relation between the average 28-day strength of the concrete and water-cement ratio shall be established for a range of values, including all of the strengths called for in the plans. The tests shall include at least four different water-cement ratios and at least four specimens for each water-cement ratio, each specimen made from a separate batch. The water-cement ratio to be used in the structure shall be that corresponding to a point on the curve, established by these tests, representing a strength of concrete 15 per cent higher than the minimum ultimate strength called for on the plans and satisfactory evidence shall be submitted to show that these water-cement ratios are not exceeded during the construction of the building. No substitution shall be made in the materials being used on the work without additional tests in accordance herewith to show the new water-cement ratios to be used.

(b) During the progress of the work, a reasonable number of additional 28-day compression tests may be required, but at least one specimen shall be tested for each 50 cubic yards of concrete of any one strength and not less than two specimens of each strength of concrete for any one day's operation. Such tests shall be made in accordance with the provisions in Sec. 9 for making field tests of concrete. Should the average strengths of the control cylinders cured moist at 70° F. shown by these tests for any portion of the structure fall below the minimum ultimate 28-day strengths called for on the plans, the architect shall have the right to order a change in the mix or the water-cement ratios for the remaining portion of the structure, but no extra claim shall be allowed for such changes. Should the average strengths shown by the cylinders cured on the job and tested subsequent to 28 days fall below the required strength, the architect shall have the right to require conditions of temperature and moisture necessary to secure the required strength.

9. *Field Tests of Concrete*

(a) Field tests of concrete, when required, shall be made in accordance with the "Standard Method of Making Compression Tests of Concrete" (Serial Designation: C39-27) of the American Society for Testing Materials, with the following exceptions:

(1) Two sets of samples of concrete for test specimens shall be taken as the concrete is being delivered at the point of deposit, care being taken to obtain a sample representative of the entire batch.

(2) One set designated as control cylinders shall be placed under moist curing conditions at approximately 70° F. within 24 hours after molding and maintained therein until tested.

(3) The second set, designated as job cylinders, shall be kept as near to the point of sampling as possible and yet receive the same protection from the elements as is given to the portions of the structure being placed. Specimens shall be kept from injury while on the work. They shall be sent to the laboratory not more than 7 days prior to the time of test and while in the laboratory shall be kept in the ordinary air at a temperature of approximately 70° F. until tested.

(b) All specimens and tests shall be made by a properly qualified person or testing laboratory, who shall furnish the architect with a certified report, showing the results of tests and stating that they were made in accordance with the provisions of this specification.

10. *Concrete Proportions and Consistency*

(a) The proportions of aggregates to cement for concrete of any water-cement ratio shall be such as to produce concrete that will work readily into the corners and angles of the form and around the reinforcement without excessive puddling or spading and without permitting the materials to segregate or free water to collect on the surface. The combined aggregate shall be of such composition of sizes that, when separated by the No. 4 standard sieve, the weight retained on the sieve shall not be less than one-third nor more than two-thirds of the total, nor shall the amount of coarse material be such as to produce harshness in placing or honeycombing in the structure. When forms are removed, the faces and corners of the members shall show smooth and sound throughout.

(b) The methods of measuring concrete materials shall be such that the proportion of water to cement can be accurately controlled during the progress of the work and easily checked at any time by the architect or his authorized representative.

MIXING AND PLACING CONCRETE

11. *Removal of Water from Excavation*

(a) Water shall be removed from excavations before concrete is deposited, unless otherwise directed by the architect. Any flow of water into the excavation shall be diverted through proper side drains to a sump, or be removed by other approved methods which will avoid washing the freshly deposited concrete. Water vent pipes and drains shall be filled by grouting, or otherwise, after the concrete has thoroughly hardened.

12. *Cleaning Forms and Equipment*

(a) Before placing concrete, all equipment for mixing and transporting the concrete shall be cleaned, all debris and ice shall be removed from the places to be occupied by the concrete, forms shall be thoroughly wetted (except in freezing weather) or oiled, and clay or cement tile that will be in contact with concrete shall be well drenched (except in freezing weather). Reinforcement shall be thoroughly cleaned of ice or other coatings.

13. *Inspection*

(a) Concrete shall not be placed until the forms and reinforcement have been inspected by the architect or engineer responsible for the design or his authorized representative.

14. *Mixing*

(a) The concrete shall be mixed until there is a uniform distribution of the materials and the mass is uniform in color and homogeneous. The mixer shall be of such type as to insure the maintaining of the correct proportions of the ingredients. The mixing shall continue for at least one minute after all the ingredients are in the mixer.

15. *Transporting*

(a) Concrete shall be handled from the mixer to the place of final deposit as rapidly as practicable by methods which will prevent the separation or loss of the ingredients. It shall be deposited as nearly as practicable in its final position to avoid rehandling or flowing. Under no circumstances shall concrete that has partially hardened be deposited in the work.

(b) When concrete is conveyed by chuting, the plant shall be of such size and design as to insure a practically continuous flow in the chute. The slope of the chute shall be such as to allow the concrete to flow without separation of the ingredients. The delivery end of the chute shall be as close as possible to the point of deposit. When the operation is intermittent, the spout shall discharge into a hopper. The chute shall be thoroughly flushed with water before and after each run; the water used for this purpose shall be discharged outside the forms.

16. *Placing*

(a) When concreting is once started, it shall be carried on as a continuous operation until the placing of the section or panel is completed.

(b) Concrete shall be thoroughly compacted by puddling with suitable tools during the operation of placing, and thoroughly worked around the reinforcement, around embedded fixtures, and into the corners of the forms.

(c) Where conditions make puddling difficult, or where the reinforcement is congested, batches of mortar containing the same proportion of cement to sand used in the concrete shall first be deposited in the forms and the operation of filling with the regularly specified mix be carried on at such a rate that the mix is at all times plastic and flows readily into the spaces between the bars.

(d) A record shall be kept on the work of the time and date of placing the concrete in each portion of the structure. Such record shall be kept until the completion of the structure and shall be open to the inspection of the architect.

NOTE:

Specifications covering finishing of concrete surfaces should be added. Methods of finishing are so varied they cannot be given in a general specification.

17. *Curing*

(a) Exposed surfaces of concrete shall be kept moist for a period of at least 7 days after being deposited. In hot weather, exposed concrete shall be thoroughly wetted at least twice daily during the first week.

18. *Depositing in Cold Weather*

(a) When depositing concrete at freezing or near freezing temperatures, the concrete shall have a temperature of at least 50° F., but not more than 120° F. The concrete shall be maintained at a temperature of at least 50° F. for not less than 72 hours after placing or until the concrete has thoroughly hardened. When necessary, concrete materials shall be heated before mixing. Dependence shall not be placed on salt or other chemicals for the prevention of freezing. No frozen materials or materials containing ice shall be used. Manure shall not be applied directly to concrete when used for protection.

FORMS AND DETAILS OF CONSTRUCTION

19. Design of Forms

(a) Forms shall conform to the shape, lines and dimensions of the member as called for on the plans. They shall be substantial and sufficiently tight to prevent leakage of mortar; they shall be properly braced or tied together so as to maintain position and shape and insure safety to workmen and passersby. Temporary openings shall be provided where necessary to facilitate cleaning and inspection immediately before depositing concrete.

20. Removal of Forms

(a) The removal of forms shall be carried out in such a manner as to insure the complete safety of the structure. Where the structure as a whole is supported on shores, removable floor forms, beams and girder sides, column and similar vertical forms may be removed within 24 hours, providing the concrete has hardened sufficiently that it is not injured. In no case shall the supporting forms be disturbed until the concrete has hardened sufficiently to permit their removal with safety. Shoring shall not be removed until the member has acquired sufficient strength to support safely its weight and the load upon it.

21. Cleaning and Bending Reinforcement

(a) Metal reinforcement, before being placed, shall be free from rust scale or other coatings that will destroy or reduce the bond. Reinforcement shall be formed to the dimensions indicated on the plans. Cold bends shall be made around a pin having a diameter of four or more times the least dimensions of the bar.

(b) Metal reinforcement shall not be bent or straightened in a manner that will injure the material. Bars with kinks or bends not shown on the plans shall not be used. Heating of reinforcement for bending will not be permitted.

22. Placing Reinforcement

(a) Metal reinforcement shall be accurately placed and secured, and shall be supported by concrete or metal chairs or spacers or metal hangers.

23. Splices and Offsets in Reinforcement

(a) In slabs, beams and girders, splices of reinforcement shall not be made at points of maximum stress without the approval of the architect. Splices, where permitted, shall provide sufficient lap to transfer the stress between bars by bond and shear.

(b) Splices in column bars shall provide a lap of 24 diameters for deformed bars and 30 diameters for plain bars.

24. Construction Joints

(a) Joints not indicated on the plans shall be so made and located as to least impair the strength of the structure. Where a horizontal joint is to be made, any excess water and laitance shall be removed from the surface after concrete is deposited. Before depositing of concrete is resumed, the hardened surface shall be cleaned and roughened and all weak concrete removed.

(b) At least 2 hours must elapse after depositing concrete in the columns or walls before depositing in beams, girders or slabs supported thereon. Beams, girders, brackets, column capitals and haunches shall be considered as part of the floor system and shall be placed monolithically therewith.

(c) Construction joints in floors shall be located near the middle of spans of slabs, beams or girders, unless a beam intersects a girder at this point, in which case the joints in the girders shall be offset a distance equal to twice the width of the beam. In this last case provision shall be made for shear by use of inclined reinforcement.

STANDARD SPECIFICATIONS AND TESTS FOR CONCRETE AND CONCRETE AGGREGATES

of the

AMERICAN SOCIETY FOR TESTING MATERIALS
PHILADELPHIA, PA.

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TENTATIVE SPECIFICATIONS FOR CONCRETE AGGREGATES

Serial Designation: C33-28T

QUALITY OF AGGREGATES

It is recognized that for certain purposes satisfactory results may be obtained with materials not conforming to these specifications. In such cases the use of fine and coarse aggregates not conforming to these specifications should be authorized only under special provisions based upon laboratory studies of the possibility of designing a mixture of materials to be used on the job that will yield concrete equivalent to the specified mixture made with material complying with these specifications in all respects.

FINE AGGREGATE

1. Fine aggregate shall consist of sand or other approved inert materials with similar characteristics, or a combination thereof, having hard, strong, durable particles and shall conform to the requirements of these specifications.

2. (*a*) The maximum percentages of deleterious substances shall not exceed the following values:

	PER CENT BY WEIGHT
Removed by decantation	3
Shale	1
Coal	1
Clay lumps	1
Other local deleterious substances (such as alkali, mica, coated grains, soft and flaky particles)	..

NOTE—It is recognized that under certain conditions maximum percentages of deleterious substances less than those shown in the table should be specified.

(*b*) The sum of the percentages of shale, coal, clay lumps, soft fragments and other deleterious substances shall not exceed 5 per cent by weight.

(*c*) All fine aggregate shall be free from injurious amounts of organic impurities. Aggregates subjected to the colorimetric test for organic impurities and producing a color darker than the standard shall be rejected unless they pass the mortar strength test as specified in Section 4.

3. (*a*) Fine aggregate shall be well graded from coarse to fine and, when tested by means of laboratory sieves[1], shall conform to the following requirements:

	PER CENT
Passing a ⅜-in. sieve	100
Passing a No. 4 sieve	(85) to (100)
Passing a No. 16 sieve	(45) to (80)
Passing a No. 50 sieve	(2) to (30)
Passing a No. 100 sieve	(0) to (5)

NOTE—Figures in parentheses are suggested as limiting percentages but they may be altered within these limits to suit local conditions.

(*b*) In case the concrete resulting from a mixture of aggregates approaching the extreme limits for gradation is not of a workable character, or when finished does not exhibit a proper surface, due to an excess of particles approximately ⅛ to ½ in. in size, either a fine aggregate having a sufficiently greater percentage of fine material, or a coarse aggregate having a sufficiently smaller percentage of fine material, must be used.

4. Fine aggregates, when subjected to the mortar strength test, shall have a tensile or compressive strength at the age of 7 and 28 days of not less than (100)[2] per cent of that developed by mortar of the same proportions and consistency made of the same cement and standard Ottawa sand.

COARSE AGGREGATE

5. Coarse aggregate shall consist of crushed stone, gravel, blast-furnace slag, or other approved inert materials of similar characteristics, or combinations thereof, having hard, strong, durable pieces, free from adherent coatings and conforming to the requirements of these specifications.

6. (*a*) The maximum percentages of deleterious substances shall not exceed the following values:

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[1] For detail requirements for these sieves, see the Standard Specifications for Sieves for Testing Purposes (Serial Designation: E-11) of the American Society for Testing Materials, 1927 Book of A.S.T.M. Standards, Part II, p. 917.

[2] Percentages in parentheses are recommended but they may be altered to suit local conditions.

	Per Cent by Weight
Removed by decantation............	1
Shale............................	1
Coal............................	1
Clay lumps......................	½
Soft fragments....................	5
Other local deleterious substances (such as alkali, friable, thin, elongated, or laminated pieces).................	..

Note—It is recognized that under certain conditions, maximum percentages of deleterious substances less than those shown in the table should be specified.

(*b*) The sum of the percentages of shale, coal, clay lumps and soft fragments shall not exceed 5 per cent by weight.

7. (*a*) Coarse aggregate shall be well graded, between the limits specified, and shall conform to the following requirements:

	Per Cent by Weight
Passing....in. Sieve or Screen (maximum size).............	not less than (95)
Passing....in. Sieve or Screen (intermediate size).... (one-half maximum size)	not less than (40) not more than (75)
Passing....in. Sieve or Screen (intermediate sizes).... (as needed)..........	not less than..... not more than....
Passing No. 4 Sieve or a ¼-in. Screen....................	not more than (10)

Note—Where a range is shown, the engineer should use an appropriate figure within the limits recommended. The percentages in parentheses are recommended but may need to be altered to suit local conditions.

(*b*) In case the concrete resulting from a mixture of aggregates approaching the extreme limits for gradation is not of a workable character, or when finished does not exhibit a proper surface, due to an excess of particles approximately ⅛ to ½ in. in size, either a fine aggregate having a sufficiently greater percentage of fine materials, or a coarse aggregate having a sufficiently smaller percentage of fine material, shall be used.

8. Blast-furnace slag that meets the grading requirements of these specifications shall conform to the following minimum weight requirements:

Base concrete..........	65 lb. per cu. ft.
Surface concrete (subject to abrasion)..	70 lb. per cu. ft.

9. Coarse aggregate shall pass a sodium sulfate accelerated soundness test, except that aggregates failing in the accelerated soundness test may be used if they pass a satisfactory freezing and thawing test.

Note—Many engineers feel that an abrasion test for coarse aggregate to be used in concrete subject to abrasion is important, but no test limits are specified, due to the status of knowledge concerning suitable specification limits for this test.

METHODS OF SAMPLING AND TESTING

10. The properties enumerated in these specifications shall be determined in accordance with the following methods of test of the American Society for Testing Materials, except as specified in Paragraphs (*e*), (*g*), (*i*) and (*j*).

(*a*) *Sampling.*—Standard Methods of Sampling Stone, Slag, Gravel, Sand and Stone Block for Use as Highway Materials, Including Some Material Survey Methods (Serial Designation: D 75).

(*b*) *Sieve Analysis.*—Standard Method of Test for Sieve Analysis of Aggregates for Concrete (Serial Designation: C 41).

(*c*) *Decantation Test.* — Tentative Method of Decantation Test for Sand and Other Fine Aggregates (Serial Designation: D 136-22 T).

(*d*) *Organic Impurities.*—Standard Method of Test for Organic Impurities in Sands for Concrete (Serial Designation: C 40).

(*e*) *Mortar Strength.*—Methods of Making Compression and Tension Tests of Fine Aggregate for Concrete as adopted by the American Association of State Highway Officials.

(*f*) *Compressive Strength.*—Standard Methods of Making Compression Tests of Concrete (Serial Designation: C 39).

(*g*) *Soundness.*—Method of Tests for Soundness of Coarse Aggregate (Sodium Sulfate Soundness Test) as adopted by the American Association of State Highway Officials.

(*h*) *Freezing and Thawing.*—Method of Freezing and Thawing Tests of Drain Tile as described in the Standard Specifications for Drain Tile (Serial Designation: C 4).

(*i*) *Shale and Coal.*—Method of Test for Percentage of Shale in Aggregate as adopted by the American Association of State Highway Officials.

(*j*) *Soft Fragments.*—Method of Test for Quantity of Soft Pebbles in Gravel as adopted by the American Association of State Highway Officials.

(*k*) *Moisture.*—Tentative Method of Test for Field Determination of Surface Moisture in Fine Aggregate (Serial Designation: C 70-27T).

(*l*) *Consistency.*—Tentative Method of Test for Consistency of Portland-Cement Concrete (Serial Designation: D 138-26T).

(*m*) *Weight of Slag.*—Standard Method of Test for Unit Weight of Aggregate for Concrete (Serial Designation: C 29).

(*n*) *Abrasion.*—If abrasion tests are made, the following methods of tests are recommended:

(1) *Abrasion of Gravel.*—Tentative Method of Test for Abrasion of Gravel (Serial Designation: D——28T)[3]

(2) *Abrasion of Rock or Crushed Slag.*—Standard Method of Test for Abrasion of Rock (Serial Designation: D2), except that for specific gravities lower than 2.2 a 4000-g. sample shall be used.

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[3] See 1928 Report of Committee D-4 on Road and Paving Materials.

STANDARD METHODS OF SAMPLING STONE, SLAG, GRAVEL, SAND AND STONE BLOCK FOR USE AS HIGHWAY MATERIALS

INCLUDING SOME MATERIAL SURVEY METHODS

Serial Designation: D75-22

These methods were approved July 18, 1924, as "Tentative American Standard" by the American Engineering Standards Committee.

1. Samples of all materials for test upon which is to be based the acceptance or rejection of the supply shall be taken by the Engineer or his authorized representative. Samples for inspection or preliminary test may be submitted by a producer or owner of the supply.

I. SAMPLING OF STONE

A. Sampling of Stone from Ledges or Quarries for Quality.

2. The ledge or quarry face shall be inspected closely to determine any variation in different layers. Any difference in color or structure shall be observed, and, if necessary to secure unweathered specimens, pieces broken from different layers.

3. (*a*) For standard stone test, separate samples shall be taken of at least 30 lb. of each of fresh unweathered specimens from all layers that appear to vary in color or structure. When more than one piece is taken, the minimum size shall be 2 in., except that there shall be one piece of each sample of a minimum size of 4 by 5 by 3 in. on which the bedding plane is marked and which shall be free from seams or fractures to be used in the toughness or compression test.

(*b*) The sample for concrete test will depend on the kind of tests to be made and the number of specimens necessary.

4. In addition to the general information accompanying all samples, samples from local ledges not commercial sources shall contain the following: Name of owner; approximate quantity available (if quantity is very large, this can be recorded as practically unlimited); amount and character of overburden or stripping; haul to nearest point on road where the material is to be used; character of haul (kind of road and grade); also some detailed record of the extent and location of the material represented by each sample. For this purpose a sketch, plan and elevation showing the thickness and location of the different layers is recommended.

B. Sampling of Stone from Commercial Quarries.

5. Where practical, samples from commercial quarries shall be taken from the ledge or quarry face and the same procedure shall be followed as when sampling local ledges.

6. At the plant, the following factors affect the size of broken stone: Size and shape of screen openings; length of screen sections; the angle of screen with

horizontal; the speed of screen rotation; and the rate at which the screen is fed. A general inspection and record of these conditions shall be made. The sample shall be taken preferably from cars or boats while loading from stock piles or bins. It is recommended, in order that the sample may be representative, that separate samples be taken at different times while the material is being loaded. If the sample has to be taken from the bin or stock pile, several samples shall be taken from different parts of the stock pile and from the top of the bin and the loading chute. These separate samples shall be well mixed in a composite sample and the sample for test obtained by the quartering method.

7. (*a*) Where it is not practical to visit the plant, samples for both quality and size shall be taken from different parts of the car or boat during unloading. It is recommended that separate samples be taken from the top, middle and bottom of car or boat. These separate samples shall be well mixed in a composite sample and the sample for test obtained by the quartering method. The results of tests on crushed stone for quality are not considered comparable with results from samples specially broken for test in the laboratory, but the general quality of the stone can be ascertained and check tests on various shipments should indicate any change in quality. In this case, tests for both quality and size can be made on the same sample.

(*b*) Where test is to be made for size only, it is recommended that a small set of screens and a pair of scales or some unit measure receptacle for measuring volume be used for field testing in order not to delay decision on the use of the material. Occasional check tests can be obtained from the laboratory to assure a fair degree of accuracy in field testing.

8. (*a*) The sample of crushed stone for mechanical analysis shall weigh at least 50 times the weight of the largest piece therein.

(*b*) The sample for concrete test will depend on the kind of tests to be made and the number of specimens necessary.

C. Sampling of Field Stone and Boulders.

9. A detailed inspection of the deposits of field stone and boulders, over the area where the supply is to be obtained, shall be made. The different kinds of stone and its state of preservation in the various deposits shall be recorded.

10. Separate samples shall be taken of all stone of different classes that a visual inspection indicates, from state of preservation and degrees of lamination, would be considered for use in construction.

11. Records accompanying samples of field stone and boulders, in addition to general information, shall contain the following:

(*a*) Location of supply;

The plotting of the field stone and boulder area on a U. S. topographic or a similar map is recommended for this purpose.

(*b*) Approximate quantity available;

A fairly accurate estimate of amount of stone in fences can be made by measuring a cross-section and pacing the length. It is more difficult to estimate the amount of stone scattered on the ground and ordinarily such deposits do not pay to work unless quite congested.

(*c*) Information regarding the percentage of different classes of stone which were sampled and the percentages of material which can be rejected by visual examination and may have to be handled and spoiled.

This information regarding the percentages of different kinds of material can only be estimated and the degree of accuracy attained will depend almost entirely upon the experience and skill of the individual.

II. SAMPLING OF BLAST-FURNACE SLAG

12. It is recommended that blast-furnace slag be sampled for size and quality by the method specified for broken stone.

III. SAMPLING OF SAND AND GRAVEL

A. Non-Commercial Deposits.

13. Non-commercial as used here includes all undeveloped sand and gravel deposits and all developed deposits where the material is not washed or screened.

14. (*a*) The investigator should realize that few if any natural sand and gravel deposits are uniform, and when a sample is taken the quantity of material in the deposit similar to the sample shall be ascertained as nearly as possible.

(*b*) Where possible, samples of sand shall be taken when it is in a damp condition.

(*c*) If the deposit is worked as a bank or pit and has an open face, the sample shall be taken by channeling the open face so as to represent material that visual inspection indicates could be used. Care shall be taken to eliminate any overburden or stripping at the top or any that has fallen along the face from the top. It is necessary, especially in small deposits, to excavate test pits some distance back of and parallel to the face to determine the extent of the supply. The number and depth of these pits depends on the quantity of material that is to be taken from the deposit. Separate samples shall be taken from the face of the bank and from test pits. These shall be well mixed in composite sample and the sample for test obtained by the quartering method.

(*d*) Deposits that have no open face shall be sampled by means of test pits. The number and depth of these will depend on local conditions and the amount of material to be used from the source. A separate sample shall be taken from each pit and where visual examination indicates no radical difference in size of grain, color, etc., these shall be well mixed in a composite sample and the sample for test obtained by the quartering method. Where visual inspection indicates a distinct difference in material from different pits, separate samples shall be taken for test.

(*e*) It is suggested that the colorimetric test be used for determining the percentage of organic material[1].

15. In addition to the general information accompanying all samples from sand and gravel deposits not commercial sources, the same detailed information shall be supplied as with samples of stone taken from local ledges.

B. Commercial Sand and Gravel Plants.

16. Samples of both sand and gravel from commercial screening or washing plants shall be taken from the bins or storage piles preferably while the material is being loaded from these supplies. The sand and gravel shall be sampled as separate units and shipped as such. It is difficult to secure a representative sample from stock piles and bins and, if conditions require sampling from these sources, the following is recommended: Separate samples shall be taken from different parts of the stock pile, care being taken to avoid sampling a segregated area of coarse-grained material which is likely to exist at the base of the pile. In sampling from a bin, separate samples shall be taken from the top and the loading chute. At the latter place at least ½ cu. yd. of material shall be run off and representative samples taken from it. These separate samples shall be well mixed in a composite sample and the sample for test obtained by the quartering method.

17. The size of sand and gravel will be affected by the same factors as broken stone and the same inspection is necessary. In addition, the relative amount of water used in screening must be taken into consideration. The same procedure for taking a sample of broken stone for size is recommended for sampling sand and gravel for size, both at plant and at delivery.

18. Where it is not practical to visit the plant, samples for both quality and size shall be taken from different parts of the car or boat during unloading. It is recommended that separate samples be taken from the top, middle and bottom of car or boat. These separate samples shall be well mixed in a composite sample and the sample for test obtained by the quartering method.

C. Quantity of Sand and Gravel Samples.

19. Samples of run of bank (where the sand and gravel are combined) shall consist of at least 100 lb. of material where the gravel content is 50 per cent or more of the whole. If the gravel is less in percentage, the sample shall be increased in proportion. For example, where the gravel percentage is 25 per cent of the whole the sample should contain 200 lb.

20. Samples of sand shall contain at least 20 lb. of material.

21. Samples of gravel shall contain at least 50 lb. of material.

22. The sample for concrete test will depend on the kind of tests to be made and the number of specimens necessary.

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[1] For a description of this test, see the Standard Method of Test for Organic Impurities in Sands for Concrete (Serial Designation:C-40) of the American Society for Testing Materials on page 57.

IV. SAMPLING OF MISCELLANEOUS MATERIALS

23. Samples of slag sand, screenings, mine tailings, and all other materials used as a substitute for sand and gravel or broken stone, shall be inspected in the same manner and samples taken in the same way as the materials for which they are substituted.

V. SAMPLING OF STONE BLOCK

24. Samples shall be taken either at the quarry or from cars or boats as directed by the Engineer. They shall be representative of the block which it is proposed to use and no sample shall include blocks that would be rejected by visual inspection.

25. The sample shall consist of at least six blocks and the bedding plane shall be marked on at least two of these.

VI. GENERAL DIRECTIONS FOR SHIPPING AND MARKING SAMPLES

26. Samples of ledge stone, crushed stone and slag shall be shipped in a secure box or bag.

27. Samples of stone block shall be securely crated.

28. Samples of run of bank gravel, sand screenings, and other fine material shall be shipped in a tight box or closely woven bag so there shall be no loss of the finer particles.

29. Each sample or separate container shall be accompanied by a card or regular form, preferably in the container, giving the following information: By whom taken, official title or rank of the sampler; by whom submitted; source of supply; proposed use for the material; and, in case of commercial supplies, daily production; geographic location, shipping facilities (name of railroad, canal or river, or other common carrier); and price of the material.

STANDARD METHOD OF TEST FOR ORGANIC IMPURITIES IN SANDS FOR CONCRETE

Serial Designation: C40-27

1. This method of test is an approximate method of determining the presence of injurious organic compounds in natural sands which are to be used in cement mortar or concrete. The principal value of the test is to furnish a warning that further tests of the sands are necessary before they are approved for use.

2. A representative test sample of sand weighing about one pound shall be obtained by quartering or by the use of a sampler.

3. (a) A 12-oz. graduated clear glass bottle shall be filled to the 4½-oz. mark with the sand to be tested.

(b) A 3 per cent solution of sodium hydroxide in water shall be added until the volume of the sand and liquid indicated after shaking is 7 liquid ounces.

(c) The bottle shall be stoppered, shaken vigorously and then allowed to stand for 24 hours.

4. A standard color solution shall be prepared by adding 2.5 cc. of a 2 per cent solution of tannic acid in 10 per cent alcohol to 97.5 cc. of a 3 per cent sodium hydroxide solution. This shall be placed in a 12-oz. bottle, stoppered, shaken vigorously, and allowed to stand for 24 hours.

5. (a) After standing 24 hours, the color of the clear liquid above the sand shall be compared with the color of the standard color solution prepared at the same time and in accordance with the method described in Section 4, or with a glass of color similar to the color of the standard solution.

(b) Solutions darker in color than the standard color have a "color value" higher than 250 parts per million in terms of tannic acid.

STANDARD METHOD OF DECANTATION TEST FOR SAND AND OTHER FINE AGGREGATES

Serial Designation: D136-28

1. This method of test covers the determination of the total quantity of silt, loam, clay, etc., in sand and other fine aggregates.[1]

2. The pan or vessel to be used in the determination shall be approximately 9 in. (230 mm.) in diameter and not less than 4 in. (102 mm.) in depth.

3. The sample must contain sufficient moisture to prevent segregation and shall be thoroughly mixed. A representative portion of the sample sufficient to yield approximately 500 g. of dried material shall then be dried to a constant weight at a temperature not exceeding 110° C. (230° F.).

4. The dried material shall be placed in the pan and sufficient water added to cover the sample (about 225 cc.). The contents of the pan shall be agitated vigorously for 15 seconds, and then be allowed to settle for 15 seconds, after which the water shall be poured off, care being taken not to pour off any sand. This operation shall be repeated until the wash water is clear. As a precaution, the wash water shall be poured through a No. 200-mesh sieve and any material retained thereon returned to the washed sample. The washed sand shall be dried to a constant weight at a temperature not exceeding 110° C. (230° F.) and weighed.

5. The results shall be calculated from the formula:

$$\text{Percentage of silt, clay, loam, etc.} = \frac{\text{Original dry wt.} - \text{wt. after washing}}{\text{Original dry wt.}} \times 100$$

6. When check determinations are desired, the wash water shall be evaporated to dryness, the residue weighed, and the percentage calculated from the formula:

$$\text{Percentage of silt, loam, clay, etc.} = \frac{\text{Weight of residue}}{\text{Original dry weight}} \times 100$$

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[1] This determination of the percentage of silt, clay, loam, etc., will include all water-soluble material present, the percentage of which may be determined separately if desired.

STANDARD METHOD OF TEST FOR SIEVE ANALYSIS OF AGGREGATES FOR CONCRETE

Serial Designation: C41-24

1. A representative test sample of the aggregate shall be selected by quartering or by use of a sampler, which, after drying, will give not less than the following:

(*a*) Fine aggregate, 500 g.

(*b*) Coarse aggregate or a mixture of fine and coarse aggregates, weight in grams, 3000 times size of largest sieve required, measured in inches.

TABLE I

Sieve No.[1] or Size in Inches	Sieve Opening		Wire Diameter		Tolerance, per cent			
	mm.	in.	mm.	in.	Average Opening	Wire Diameter		Maximum Opening
						Under	Over	
No. 100..	0.149	0.0059	0.102	0.0040	6	15	35	40
No. 50...	0.297	0.0117	0.188	0.0074	6	15	35	40
No. 30...	0.59	0.0232	0.33	0.0130	5	15	30	25
No. 16...	1.19	0.0469	0.54	0.0213	3	15	30	10
No. 8....	2.38	0.0937	0.84	0.0331	3	15	30	10
No. 4....	4.76	0.187	1.27	0.050	3	15	30	10
⅜-in.....	9.5	0.375	2.33	0.092	3	10	10	10
¾-in.....	19.0	0.75	3.42	0.135	3	10	10	10
1-in......	25.4	1.00	4.12	0.162	3	10	10	10
1½-in....	38.0	1.50	4.50	0.177	3	10	10	10
2-in......	50.8	2.00	4.88	0.192	3	10	10	10
3-in......	76.0	3.00	6.3	0.25	3	10	10	10

2. The sample shall be dried at not over 110° C. (230° F.) to constant weight.

3. (*a*) The sieves shall be of square-mesh wire-cloth and shall be mounted on substantial frames constructed in

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[1] The requirements for sieves No. 100 to No. 4 conform to the requirements of the U. S. Standard Sieve Series as given in U. S. Bureau of Standards *Letter Circular No. 74*. The liberal tolerances will permit the use of certain sieves which do not exactly correspond to the numbers given in table.

a manner that will prevent loss of material during sifting.

(*b*) The size of wire and sieve openings shall be as given in Table I.

4. (*a*) The samples shall be separated into a series of sizes by means of the sieves specified in Section 3. Sifting shall be continued until not more than 1 per cent by weight of the sample passes any sieve during 1 minute.

(*b*) Each size shall be weighed on a balance or scale which is sensitive to 1/1000 of the weight of the test sample.

(*c*) The percentage by weight of the total sample which is finer *than each* of the sieves shall be computed.

5. (*a*) The percentages in sieve analysis shall be reported to the nearest whole number.

(*b*) If more than 15 per cent of a fine aggregate is coarser than the No. 4 sieve or more than 15 per cent of a coarse aggregate is finer than the No. 4 sieve, the sieve analysis of the portions finer and coarser than this sieve shall be reported separately.

STANDARD METHOD OF TEST
FOR
UNIT WEIGHT OF AGGREGATE FOR CONCRETE

Serial Designation: C29–27

1. This method is intended to cover the determination of unit weight of fine, coarse, or mixed aggregate for concrete.

2. (a) The apparatus required consists of a cylindrical metal measure, a tamping rod, and a scale or balance, sensitive to 0.5 per cent of the weight of the sample to be weighed.

(b) Measures.—The measure shall be of metal, preferably machined to accurate dimensions on the inside, cylindrical in form, watertight, and of sufficient rigidity to retain its form under rough usage, with top and bottom true and even, and preferably provided with handles.

The measure shall be of 1/10, ½ or 1-cu. ft. capacity, depending on the maximum diameter of the coarsest particles in the aggregate, and shall be of the following dimensions:

Capacity, cu. ft.	Inside Diameter Inches	Inside Height Inches	Minimum Thickness of Metal U. S. Gage	Diameter of Largest Particles of Aggregate Inches
1/10	6.00	6.10	No. 11	Under ½
½	10.00	11.00	No. 8	Under 1½
1	14.00	11.23	No. 5	Over 1½

(c) Tamping Rod.—The tamping rod shall be a straight metal rod ⅝ in. in diameter and 24 in. in length, with one end tapered for a distance of 1 in. to a blunt bullet-shaped point.

3. The measure shall be calibrated by accurately determining the weight of water at 16.7° C. (62° F.) required to fill it. The factor for any unit shall be obtained by dividing the unit weight of water at 16.7° C. (62° F.) (62.355 lb. per cu. ft.) by the weight of water at 16.7° C. (62° F.) required to fill the measure.

4. The sample of aggregate shall be room dry and thoroughly mixed.

5. (a) The measure shall be filled one-third full and the top leveled off with the fingers. The mass shall be puddled with the tamping rod with 25 strokes evenly distributed over the surface. The measure shall be filled two-thirds full and again puddled with 25 strokes as before. The measure shall then be filled to overflowing, puddled 25 times, and the surplus aggregate struck off, using the tamping rod as a straight edge.

In puddling the first layer, the rod should not be permitted to forcibly strike the bottom of the measure. In puddling the second and final layers, only enough force to cause the tamping rod to penetrate the last layer of aggregate placed in the measure should be used.

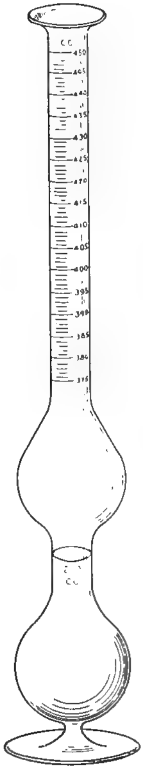
(b) The net weight of the aggregate in the measure shall be determined. The unit weight of the aggregate shall then be obtained by multiplying the net weight of the aggregate by the factor found as described in Section 3.

6. Results with the same sample should check within 1 per cent.

TENTATIVE METHOD OF TEST FOR FIELD DETERMINATION OF APPROXIMATE APPARENT SPECIFIC GRAVITY OF FINE AGGREGATE

Serial Designation: C68-28T

1. This method of test is intended for use in the field for making approximate determinations of the apparent specific gravity of fine aggregate.



Volume of lower chamber to mark on lower neck—200 cc.

Combined volume of lower and upper chambers to lower end of graduated scale on upper neck—375 cc.

Scale graduated in 1 cc. divisions from 375 cc. to 450 cc.

Diameter of opening in lower neck, approximately ⅞".

Diameter of bore of graduated upper neck, approximately ¾".

Range of use: From dry sand of 2.8 sp. gr. to sand of 2.2 sp. gr., having 10 per cent moisture.

Fig. 1—Graduated Flask for Field Testing of Fine Aggregate.

2. The apparatus shall consist of the following:

(*a*) *Balance.*—A balance, preferably of the torsion type, having a capacity of 2 kg. or more and sensitive to 0.5 g. or less.

(*b*) *Flask.*—A special graduated flask of the type, and conforming to the dimensions, shown in Fig. 1.

3. A 1-kg. sample shall be selected which shall be as truly representative of the fine aggregate as possible. It shall be spread out on a flat surface and air dried until the surface moisture has evaporated and the sample is free flowing. The sample shall then be thoroughly mixed and 500 g. accurately weighed out.

4. The graduated flask shall be filled to the 200-cc. mark on the lower neck with water at room temperature. The 500-g. sample of fine aggregate shall then be slowly poured into the flask, and the flask and contents agitated while introducing the aggregate to free any entrained air bubbles. The combined volume in cubic centimeters of the water and fine aggregate shall be read on the scale on the upper neck of the flask.

5. The approximate apparent specific gravity of the fine aggregate may be calculated from the formula:

$$\text{Approximate apparent specific gravity} = \frac{500}{V - 200}$$

where V = the combined volume in cubic centimeters of the water and fine aggregate in the flask.

6. Duplicate determinations should check to within 0.05. Variations in the amount of water evaporated from the moist sample as described in Section 3

beyond the point at which the surface moisture has disappeared and the sample is free flowing and apparently dry will cause variations in results of from 0.5 to 1 per cent depending upon the absorption of the aggregate.

TENTATIVE METHOD OF TEST FOR FIELD DETERMINATION OF APPROXIMATE PERCENTAGE OF VOIDS IN FINE AGGREGATE

Serial Designation: C69-28T

1. This method of test is intended for use in the field for making approximate determinations of the percentage of voids in fine aggregate when inundated with water.

2. The apparatus shall consist of the following:

(*a*) *Balance.*—A balance, preferably of the torsion type, having a capacity of 2 kg. or more and sensitive to 0.5 g. or less.

(*b*) *Flask.*—A special graduated flask of the type and conforming to the dimensions shown in Fig. 1. (*See page 60.*)

3. A sample weighing about 2 kg. shall be selected which shall be as truly representative of the fine aggregate as possible. It shall be well mixed and spread out on a flat surface and air dried until the surface moisture has evaporated and the sample is free flowing.

4. About 100 cc. of water shall be placed in the flask. Aggregate from the room-dry sample shall then be introduced slowly into the flask until the flask is filled to the 400-cc. mark on the upper neck. Water shall be added as required to keep the aggregate inundated as the filling proceeds. When the flask is filled to the 400-cc. mark, both water and aggregate shall be at the same level. The aggregate in the flask shall not be agitated during or after the filling operation. The flask and contents shall be weighed to the nearest gram, and the weight of the flask shall be deducted, unless its weight has been counter-balanced on the scale at the time of weighing.

5. (*a*) This method requires that the apparent specific gravity be known of the fine aggregate in a room-dry, free flowing condition, but with the voids within the particles of the aggregate containing moisture. If the apparent specific gravity of the aggregate in this condition is not known, it shall be determined in accordance with the Tentative Method of Test for Field Determination of Approximate Apparent Specific Gravity of Fine Aggregate (Serial Designation: C68-28T) of the American Society for Testing Materials.

(*b*) The approximate percentage of voids in the inundated fine aggregate may be calculated from the formula:

$$V = \frac{400 \times \text{sp. gr.} - W}{400\,(\text{sp. gr.} - 1)} \times 100$$

where V = the approximate percentage of voids;

sp. gr. = apparent specific gravity of the fine aggregate;

W = combined weight in grams of 400 cc. of water and fine aggregate in the flask.

6. Duplicate determinations should check to within 1 per cent. Variations in the composition of the rock grains of the fine aggregate which result in variations of 0.05 in the approximate apparent specific gravity of the aggregate will cause an inaccuracy in results equal to from 2 to 3 per cent of voids.

TENTATIVE METHOD OF TEST FOR FIELD DETERMINATION OF SURFACE MOISTURE IN FINE AGGREGATE

Serial Designation: C70-28T

1. This method of test is intended for use in the field for making approximate determinations of the percentage of surface moisture in fine aggregate for use in computing the allowance to be made for water in the fine aggregate when proportioning concrete by the maximum water content method.

This method determines only surface moisture, that is, moisture on the outside of the particles. The moisture absorbed within the particles does not add to the volume of the particles and, therefore, does not make itself evident in this test.

2. The apparatus shall consist of the following:

(*a*) *Balance.*—A balance, preferably of the torsion type, having a capacity of 2 kg. or more and sensitive to 0.5 g. or less.

(*b*) *Flask.*—A special graduated flask of the type and conforming to the dimensions shown in Fig. 1. (*See page 60.*)

3. A sample weighing about 1 kg. shall be selected which shall be as truly representative of the fine aggregate as possible. It shall be well mixed and spread out on a flat non-absorbent surface. Five hundred grams shall be immediately weighed out, permitting moisture to evaporate as little as possible from the sample.

4. The graduated flask shall be filled to the 200-cc. mark on the lower neck with water at room temperature. The 500-g. sample of damp aggregate shall then be slowly poured into the flask, and the contents of the flask agitated or stirred to free any entrained air bubbles. The combined volume, in cubic centimeters, of the water and fine aggregate shall be read on the scale on the upper neck of the flask.

5. (*a*) This method requires that the apparent specific gravity be known of the fine aggregate in a room-dry, free flowing condition, but with the voids within the particles of the aggregate containing moisture. If the apparent specific gravity of the aggregate in this condition is not known, it shall be determined in accordance with the Tentative Method of Test for Field Determination of Approximate Apparent Specific Gravity of Fine Aggregate (Serial Designation: C68-28T) of the American Society for Testing Materials.

(*b*) The percentage of surface moisture in the fine aggregate (air dry basis) may be calculated from the formula:

$$\text{Percentage of surface moisture} = \frac{V - \dfrac{500}{\text{sp. gr.}} - 200}{200 + 500 - V} \times 100$$

where V = the combined volume in cubic centimeters of the water and fine aggregate in the flask;

sp. gr. = approximate apparent specific gravity of the fine aggregate.

6. Duplicate determinations should check to within 0.5 per cent. Variations in the composition of the rock grains of the fine aggregate which result in variations of 0.05 in the approximate apparent specific gravity of the aggregate will cause inaccuracy in results equal to from 1 to 1.5 per cent of moisture.

STANDARD METHOD OF TEST
FOR
APPARENT SPECIFIC GRAVITY* OF COARSE AGGREGATES

Serial Designation: D30-18

This method was approved July 18, 1924, as "Tentative American Standard" by the American Engineering Standards Committee.

The apparent specific gravity shall be determined in the following manner:

1. The sample, weighing 1000 g. and composed of pieces approximately cubical or spherical in shape and retained on a screen having 1.27-cm. (½ in.) circular openings, shall be dried to constant weight at a temperature between 100 and 110° C. (212 and 230° F.), cooled, and weighed to the nearest 0.5 g. Record this weight as weight A. In the case of homogeneous material, the smallest particles in the sample may be retained on a screen having 1¼-in. circular openings.

2. Immerse the sample in water for 24 hours, surface-dry individual pieces with aid of a towel or blotting-paper, and weigh. Record this weight as weight B.

3. Place the sample in a wire basket of approximately ¼-in. mesh, and about 12.7 cm. (5 in.) square and 10.3 cm. (4 in.) deep, suspend in water from center of scale pan, and weigh. Record the difference between this weight and the weight of the empty basket suspended in water as weight C. (Weight of saturated sample immersed in water.)

4. The apparent specific gravity shall be calculated by dividing the weight of the dry sample (A) by the difference between the weights of the saturated sample in air (B) and in water (C) as follows:

$$\text{Apparent specific gravity} = \frac{A}{B-C}$$

5. Attention is called to the distinction between apparent specific gravity and true specific gravity. Apparent specific gravity includes the voids in the specimen and is, therefore, always less than or equal to, but never greater than, the true specific gravity of the material.

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*See page 71 for A. A. S. H. O. method.

TENTATIVE METHOD OF TEST
FOR
CONSISTENCY OF PORTLAND CEMENT CONCRETE

Serial Designation: D138-26T

1. This test covers the method to be used both in the laboratory and in the field for determining consistency of concrete.

2. The test specimen shall be formed in a mold of No. 16 gage galvanized metal in the form of the lateral surface of the frustum of a cone with the base 8 in. in diameter, the upper surface 4 in. in diameter, and the altitude 12 in. The base and the top shall be open and parallel to each other and at right angles to the axis of the cone. The mold shall be provided with foot pieces and handles as shown in Fig. 1.

3. When the test is made at the mixer, the sample shall be taken from the pile of concrete immediately after the entire batch has been discharged. When testing concrete that has been hauled from a central mixing plant, the sample shall be taken from the concrete immediately after it has been dumped on the subgrade.

4. The mold shall be placed on a flat, non-absorbent surface, such as a smooth plank or a slab of concrete, and the operator shall hold the form firmly in place while it is being filled by standing on the foot pieces. The mold shall be filled to about one-fourth of its height

with the concrete, which shall then be puddled, using 25 strokes of a ⅝-in. rod pointed at the lower end. The filling shall be completed in successive layers similar to the first and the top struck off so that the mold is exactly filled. The mold shall then be removed by being raised vertically immediately after being filled. The molded concrete shall then be allowed to subside until quiescent and the height of the specimen measured.

5. The consistency shall be recorded in terms of inches of subsidence of the specimen during the test, which shall be known as the slump.

Slump = 12—inches of height after subsidence.

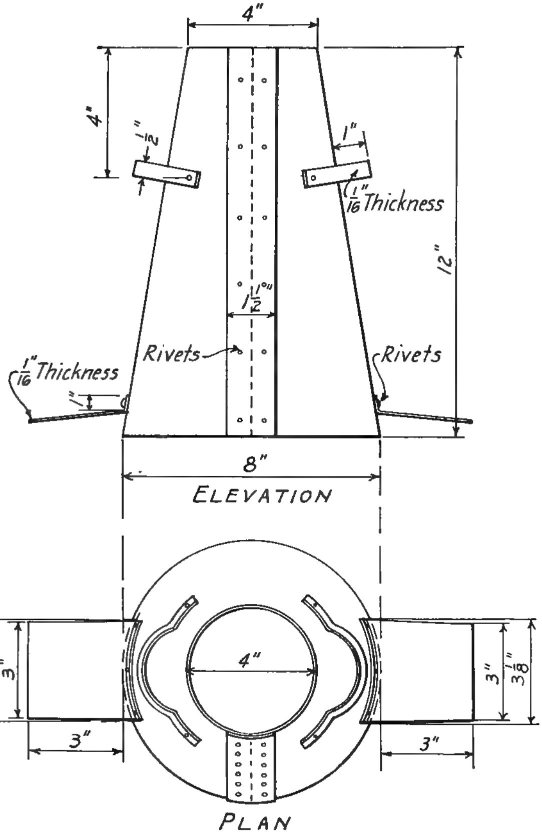


Fig. 1

STANDARD METHOD
OF
MAKING AND STORING SPECIMENS OF CONCRETE IN THE FIELD

Serial Designation: C31-27

1. This method is intended to apply to the molding and storing of test specimens of concrete sampled from concrete being used in construction.

2. The test specimens shall be cylindrical in form with the length twice the diameter. The standard shall be 6 by 12-in. cylinders where the coarse aggregate does not exceed 2 in. in size; for aggregates larger than 2 in., 8 by 16-in. cylinders shall be used; 2 by 4-in. cylinders may be used for mixtures without coarse aggregate.

3. (a) The molds shall be cylindrical in form, made of non-absorbent material, and shall be substantial enough to hold their form during the molding of the test specimens. They shall not vary in diameter more than $\frac{1}{16}$ in. in any direction, nor shall they vary in height more than $\frac{1}{16}$ in. from the height required. They shall be substantially watertight so that there will be no leakage of water from the test specimen during molding.

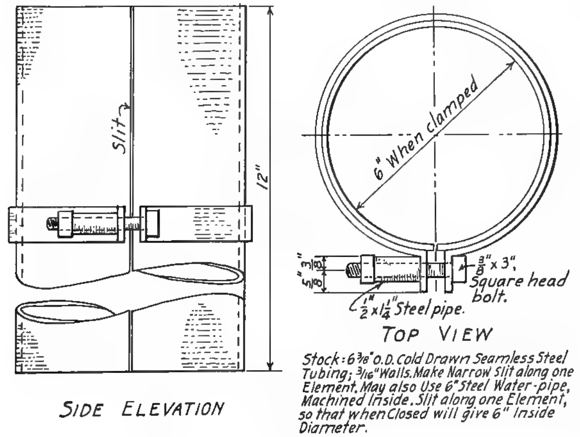
NOTE.—The best type of mold consists of lengths of cold-drawn steel tubing, split along one element and closed by means of a circumferential band and bolt. Satisfactory molds can be made from lengths of steel water pipe machined on the inside, from rolled metal plates, from galvanized steel, machined iron or steel castings. Paraffined cardboard molds will give good results under expert supervision.

(b) Each mold shall be provided with a base plate having a plane surface and made of non-absorbent material. This plate shall be large enough in diameter to properly support the mold without leakage. Plate glass or planed metal is satisfactory for this purpose. A similar plate should be provided for covering the top surface of the test specimen when molded.

(c) Suggestions for suitable molds are shown in Figs. 1 and 3. (Figure 2 omitted from this text.)

4. (a) Concrete for the test specimens shall be taken immediately after it has been placed in the work. All the concrete for each sample shall be taken from one place. A sufficient number of samples—each large enough to make one test specimen—shall be taken at different points so that the test specimens made from them will give a fair average of the concrete placed in that portion of the structure selected for tests. The location from which each sample is taken shall be noted clearly for future reference.

(b) In securing samples, the concrete shall be taken from the mass by a shovel or similar implement and placed in a large pail or other receptacle for transporting to the place of molding. Care shall be taken to see that each test specimen represents the total mixture of the concrete from a given place. Different samples shall not be mixed together but each sample shall make one specimen.



Stock: 6 3/8" O.D. Cold Drawn Seamless Steel Tubing; 3/16" Walls. Make Narrow Slit along one Element. May also Use 6" Steel Water-pipe, Machined Inside. Slit along one Element, so that when Closed will give 6" Inside Diameter.

Fig. 1

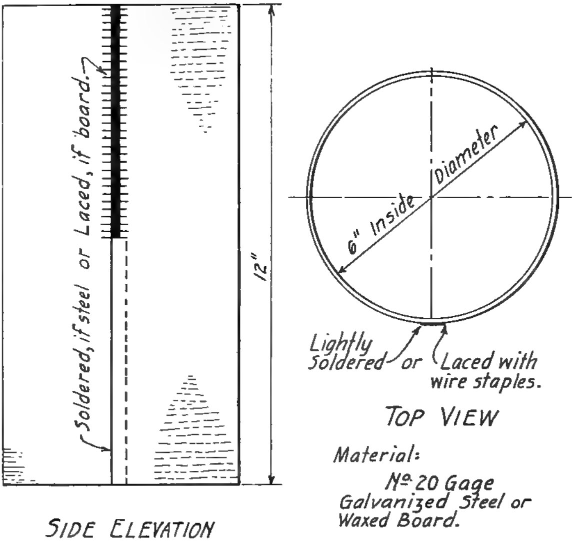


Fig. 3

5. (a) The pails or other receptacles containing the samples of concrete shall be taken as quickly as possible to the place selected for molding test specimens. To offset segregation of the concrete occurring during transportation, each sample shall be dumped into a non-absorbent watertight receptacle and, after slight mixing, immediately placed in the mold.

(b) The test specimens shall be molded by placing the concrete in the mold in layers 3 to 4 in. in thickness. Each layer shall be puddled with 25 strokes with a ⅝-in. rod 24 in. in length, bullet-pointed at the lower end. After puddling the top layer, the surface concrete shall be struck off with a trowel and covered with the top cover plate which may later be used in capping the test specimen.

6. Two to four hours after molding, the test specimens shall be capped with a thin layer of stiff neat-cement paste in order that the cylinder may present a smooth end for testing. The cap shall be formed by means of a piece of plate glass ¼ in. in thickness or a machined metal plate ½ in. in thickness and of a diameter 2 or 3 in. larger than that of the mold. The plate shall be worked on the fresh cement paste until it rests on top of the mold. The cement for capping should be mixed to a stiff paste 2 to 4 hours before it is to be used in order to avoid the tendency of the cap to shrink. Adhesion of the concrete to the top and bottom plates may be avoided by oiling the plates or by inserting a sheet of paraffined paper.

7. At the end of 48 hours the test specimens shall be removed from the molds and buried in damp sand, except in case the molds shown in Fig. 3 are used, when they may be buried in damp sand without removal of the mold, thus permitting shipping in the molds.

8. (a) The test specimens shall remain buried in damp sand until 10 days prior to the date of test. They shall then be well packed in damp sand or wet shavings and shipped to the testing laboratory, where they shall be stored either in a moist room or in damp sand until the date of test.

(b) Should a 7-day test be required, the test specimens shall remain at the work as long as possible to harden and then shall be shipped so as to arrive at the laboratory in time for test on the required date.

(c) Test specimens shall be protected from drying after removal from damp storage and before testing.

STANDARD METHODS
OF
SECURING SPECIMENS OF HARDENED CONCRETE FROM THE STRUCTURE

Serial Designation: C42-27

1. These methods and precautions are intended to apply to securing test specimens from hardened concrete in the structure.

2. A specimen from hardened concrete to be tested for strength shall not be taken until the concrete has become hard enough so that the cutting of the specimen will not disturb the bond between the mortar and the coarse aggregate of the specimen.

3. The specimen from the structure can best be secured by use of a core drill. For specimens taken perpendicular to a horizontal surface, a drill using chilled shot may be used; but when taken perpendicular to a vertical surface, a diamond drill should be used.

4. (a) The core specimen taken shall be as nearly as possible a cylinder whose length is twice the diameter.

(b) In securing a specimen perpendicular to a horizontal surface care shall be taken to secure, if possible, a specimen whose beds shall be parallel to the horizontal bed of the concrete as originally placed.

(c) In securing a specimen perpendicular to a vertical surface, or to a surface with a batter, care shall be taken as to the place of securing the specimen. The lower portion of any one unit of depositing in mass concrete is more dense than is the upper portion of the unit, therefore a specimen shall be taken from near the middle of such unit of deposit.

5. A specimen to be taken from hardened concrete which has been removed from a structure shall be cut out by a drill or shall be cut into a symmetrical test-piece by tooling or by sawing. The method of sawing can seldom be used to advantage in the field. In selecting this test specimen care shall be used to see that the concrete selected has not been injured or shattered by the method of its removal from the structure.

6. The specimen secured shall have ends, or beds, as nearly as possible perpendicular to its axis, and, if the specimen has ends with uneven surfaces, these ends shall be made to parallel plane surfaces by capping with a thin layer of mortar richer than the mortar of the specimen or with a mixture of cement and calcined gypsum (plaster of Paris).

7. In case the dimensions of a specimen are necessarily appreciably different from the recommended shape which requires a height twice the diameter, allowance for the ratio of height to diameter must be made in determining the strength. When the height is more than twice the diameter, that is, when the ratio is greater than two, no correction need be made. For other ratios corrections shall be made as indicated in the following table. Values not given in the table shall be determined by interpolation:

Ratio of Height of Cylinder to Diameter $\left\{\frac{h}{d}\right\}$	Multiply Crushing Strength by
1.75	0.98
1.50	0.95
1.25	0.94
1.10	0.90
1.00	0.85
0.75	0.70
0.50	0.50

8. The direction of the application of the load in the compression test shall be stated with reference to the direction of the compaction of the mass of concrete in the structure, and where it is practicable the compression load shall be applied in the same direction. In order that the tests be made under uniform conditions as to moisture content, the test specimens shall be completely submerged in water for 48 hours and the compression test shall be made immediately thereafter.

STANDARD METHODS
OF
MAKING COMPRESSION TESTS OF CONCRETE

Serial Designation: C39-27

1. These methods are intended to cover compression tests of concrete made in a laboratory where accurate control of quantities of materials and test conditions is possible. They are designed to apply primarily to hand-mixed concrete compression specimens, but may be used with slight modification in making tests of concrete for wearing resistance, bond between concrete and steel, impermeability, etc. The investigation of machine-mixed concrete will require certain obvious changes in the methods. For methods of conducting compression tests of concrete specimens made during the progress of construction work, see the Standard Method of Making and Storing Specimens of Concrete in the Field (Serial Designation: C 31) of the American Society for Testing Materials.

2. Materials shall be brought to room temperature (18 to 24° C., 65 to 75° F.) before beginning the tests. Cement shall be stored in a dry place; preferably in covered metal cans. The cement shall be thoroughly mixed in advance in order that the sample may be uniform throughout the tests. It shall be sieved through a No. 16 (1190-micron) sieve and all lumps rejected. Aggregates shall be in a room-dry condition when used in concrete tests. In general, aggregates should be separated on the No. 4 (4760-micron), ⅜-in. and 1½-in. sieves and recombined to the average original sieve analysis for each batch. Fine aggregate should be separated into different sizes also in cases where unusual gradings are being studied.

3. Representative samples of all concrete materials shall be secured for preliminary tests prior to the proportioning and mixing of the concrete. Cement test samples may be made up of a small quantity from each sack used in the concrete tests. Test samples of aggregates may be taken from larger lots by quartering.

4. Cement shall be tested in accordance with the methods described in the Standard Specifications and Tests for Portland Cement (Serial Designation: C 9) of the American Society for Testing Materials.

5. Fine aggregates (passing through a No. 4 (4760-micron) sieve) shall be subjected, when required, to the following tests of the American Society for Testing Materials:

(a) Sieve analysis test made in accordance with the Standard Method of Test for Sieve Analysis of Aggregates for Concrete (Serial Designation: C 41).

(b) Test for organic impurities made in accordance with the Standard Method of Test for Organic Impurities in Sand for Concrete (Serial Designation: C 40).

(c) Test for quantity of silt, clay and dust made in accordance with the Tentative Method of Decantation Test for Sand and Other Fine Aggregates (Serial Designation: D 136-22T).

(d) Test for unit weight made in accordance with the Standard Method of Test for Unit Weight of Aggregate for Concrete (Serial Designation: C 29).

(e) Strength test of 1-3 mortar by weight at 7 and 28 days in comparison with standard sand mortar in accordance with Standard Specifications and Tests for Portland Cement (Serial Designation: C 9).

6. Coarse aggregates (retained on a No. 4 (4760-micron) sieve) shall be subjected when required to the following tests:

(a) Sieve analysis test as specified in Section 5 (a).

(b) Test for quantity of silt, clay and dust made in accordance with Standard Method of Test for Quantity of Clay and Silt in Gravel for Highway Construction (Serial Designation: D 72) of the American Society for Testing Materials.

(c) Test for unit weight as specified in Section 5 (d).

7. The unit weight of mixed fine and coarse aggregates as used in concrete tests shall be determined in accordance with the method specified in Section 5 (d).

8. The quantities of each size of aggregate to be used in each batch shall be determined on the basis of the sieve analysis and the unit weight of the mixed aggregate. The exact quantities of cement and of each size of aggregate for each batch shall be determined by weight. The quantity of water for each batch shall be accurately measured. The quantities of materials may be expressed as (a) 1 volume of cement to ......volumes of total aggregate mixed as used or (b) 1 volume of cement, ...volumes of fine aggregate, and ......volumes of coarse aggregate, or (c) 1 part by weight of cement...... parts by weight of fine aggregate, and ......parts by weight of coarse aggregate.

NOTE—It is impracticable to give a general method for proportioning concrete for experimental purposes; the details will necessarily vary widely with the purpose for which the tests are made. The following procedure is suggested for specific cases:

(a) Vary the cement content by 10 per cent intervals above and below assumed quantity.

(b) Vary the proportions of fine to coarse aggregate, measured separately, at intervals of 10 per cent.

(c) Vary the quantity of mixing water by intervals of 10 per cent.

9. Compression tests of concrete shall be made on cylinders of diameter equal to one-half the length. The standard shall be 6 by 12-in. cylinders where the coarse aggregate does not exceed 2 in. in size; for aggregates larger than 2 in., 8 by 16-in. cylinders shall be used; 2 by 4-in. cylinders may be used for mixtures without coarse aggregate.

10. (a) Concrete shall be mixed by hand in batches of such size as to leave a small quantity of concrete after molding a single test specimen. The batch shall preferably be mixed in a shallow metal pan with a 10-inch bricklayer's trowel which has been blunted by cutting off about 2½ in. of the point, as follows:

(b) The cement and fine aggregate shall be mixed dry until the mixture is homogeneous in color;

(c) The coarse aggregate shall be added and mixed dry;

(d) Sufficient water shall be added to produce concrete of the required workability.

NOTE—Concrete tests should be made on plastic mixtures. It is of the utmost importance that a uniform degree of workability be secured in tests involving comparisons of different materials and methods.

(e) The mass shall be mixed thoroughly until the resulting concrete is homogeneous in appearance.

11. The workability or plasticity of each batch of concrete shall be measured immediately after mixing by one of the following methods:

(a) Slump test made in accordance with the Tentative Method of Test for Consistency of Portland Cement Concrete (Serial Designation: D 138-26T) of the American Society for Testing Materials.

(b) Flow test made by placing a metal mold in the shape of a frustum of a cone 6¾ in. in top diameter, 10 in. in bottom diameter, 5 in. in depth, on the table of the flow apparatus. The fresh concrete shall be placed in the mold in two layers. Each layer shall be puddled as described in Section 13. Immediately after molding the surplus concrete shall be struck off with a trowel and the mold shall be removed by a steady upward pull; the table raised ½ in. and dropped 15 times in about 10 seconds by means of a suitable cam and crank. The spread of the fresh concrete due to this treatment expressed as a percentage of the original bottom diameter of the cone is the "flow."

12. The molds shall preferably be of metal. Each mold shall be provided with a machined metal base plate, and shall be oiled with a heavy mineral oil before using. Particular care shall be taken to obtain tight molds so that the mixing water will not escape during molding.

NOTE—The best type of mold consists of lengths of cold-drawn steel tubing, split along one element and closed by means of a circumferential band and bolt. Satisfactory molds can be made from lengths of steel water-pipe machined on the inside, from rolled metal plates, from galvanized steel, machined iron or steel castings. Paraffined cardboard molds will give good results under expert supervision.

13. Concrete test specimens shall be molded by placing the fresh concrete in the mold in layers 3 to 4 in. in thickness.

Each layer shall be puddled with 25 strokes with a ⅝-in. rod 24 in. in length, bullet-pointed at the lower end. After the top layer has been puddled, the surplus concrete shall be struck off with a trowel, and the mold covered with a piece of plate glass at least ¼ in. in thickness or a machined metal plate which will be used later in capping the test specimen.

14. Two to four hours after molding, the test specimens shall be capped with a thin layer of stiff neat-cement paste in order that the cylinder may present a smooth end for testing. The cap shall be formed by means of a piece of plate glass ¼ in. in thickness or a machined metal plate ½ in. in thickness and of a diameter 2 or 3 in. larger than that of the mold. The plate shall be worked on the fresh cement paste until it rests on top of the mold. The cement for capping should be mixed to a stiff paste 2 to 4 hours before it is to be used in order to avoid the tendency of the cap to shrink. Adhesion of the concrete to the top and bottom plates may be avoided by oiling the plates or by inserting a sheet of paraffined paper.

15. Concrete test specimens shall be removed from the molds 20 to 48 hours after molding, marked, weighed and stored in damp sand, under damp cloths or in a moist chamber until the date of test. The temperature of the curing room should not fall outside the range of 18 to 24° C. (60 to 75° F.)

16. Tests shall be made at the age of 7 and 28 days; ages of 3 months and 1 year are recommended if longer-time tests are required.

17. Three to five test specimens should be made on different days in investigations in which accurate comparisons are desired.

18. Compression tests shall be made immediately upon removal of the concrete test specimens from the curing room; that is, the test specimens shall be loaded in a damp condition. The length and average diameter of the test specimen shall be measured in inches and hundredths; two diameters shall be measured at right angles near the midlength. The test specimen shall be weighed immediately before testing.

19. In general, only the ultimate compressive strength of the cylinders need be observed. The metal bearing plates of the testing machine shall be placed in contact with the ends of the test specimen; cushioning materials shall not be used. An adjustable bearing block shall be used to transmit the load to the test specimen. The bearing block shall be used on top of the specimen in vertical testing machines. The diameter of the bearing block shall be the same or slightly larger than that of the test specimen. The upper or lower section of the bearing block shall be kept in motion as the head of the testing machine is brought to a bearing on the test specimen.

20. The load shall be applied uniformly and without shock. The moving head of the testing machine should travel at the rate of about 0.05 in. per minute when the machine is running idle.

21. The total load indicated by the testing machine at failure of the test specimen shall be recorded and the unit compressive strength calculated in pounds per square inch, the area computed from the average diameter of the cylinder being used. The type of failure and appearance of the concrete shall be noted.

22. The weight of the concrete in pounds per cubic foot shall be determined from the weight of the specimens and their dimensions.

23. Density and yield of concrete when required shall be calculated from the unit volumes of the constituent materials and the volume of the fresh or set concrete as desired. Density is here understood to be the ratio of solids in the concrete to the total volume of the mass. Yield is the volume of concrete resulting from the volume of aggregate mixed as used.

24. The report shall include the following:

(a) The kind and origin of concrete materials;

(b) Complete data on all tests of cement and aggregates;

(c) A description of methods of making and testing the concrete where methods deviate from the proposed standards;

(d) The quantities of cement, aggregates and water in each batch;

(e) The method of measuring workability or plasticity with "slump" or "flow" of concrete;

(f) The quantity of water expressed as a ratio to volume of cement;

(g) The age at tests;

(h) The size of test specimens;

(i) The date of molding and testing each cylinder;

(j) The compressive strength in pounds per square inch of each test specimen and the average of tests in a set;

(k) A description of failure and appearance of concrete on each test specimen;

(l) The unit weight, density and yield of the concrete.

SEDIMENTATION TEST FOR APPROXIMATE QUANTITY OF CLAY AND SILT IN SAND

This test is not an A.S.T.M. Standard

A test that is often used in the field is the sedimentation test which shows the approximate quantity of clay and silt in sand. This test is made as follows:

A 32-ounce, graduated prescription bottle is filled to the 14-ounce mark with sand and clear water added to the 28-ounce mark. This mixture is then shaken vigorously and the contents allowed to settle for one hour. If more than 1 ounce of sediment then appears above the aggregate, the sand should be rejected. The sand may be subjected to washing and samples again tested and the sand approved for use if the test requirements are fulfilled.

TEST FOR APPARENT SPECIFIC GRAVITY AND ABSORPTION OF STONE AND OTHER COARSE MATERIALS

Adopted by American Association of State Highway Officials

The apparent specific gravity shall be obtained by weighing the water displaced by a sample of the material weighing approximately 1,000 grams, broken into pieces about 1¼ inches in diameter. The vessel to be used consists of a galvanized iron cylinder closed at one end and measuring 5 inches in diameter by 8 inches high. A brass spout one-half inch in diameter is soldered into the side of the cylinder 6 inches from the bottom. The spout is inclined at an angle of 2° with the horizontal and is 2½ inches long. A notch is filed across its lower end to stop the drip from the displaced water. To determine the specific gravity and absorption, the dried and cooled sample shall be weighed to the nearest 0.5 gram and immersed in water for 24 hours. The pieces shall then be surface dried individually with a towel, the sample reweighed and immediately placed in the cylinder, which has been previously filled to overflowing with water at room temperature.

The weight of water displaced by the sample shall be used to calculate its apparent specific gravity. The difference between the original weight of the sample and its weight after 24 hours shall be used to determine the absorption.

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